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Child Behavior, Animal Behavior, and Comparative Psychology

EDITED BY
CARL MURCHISON

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GENETIC PSYCHOLOGY MONOGRAPHS

Child Behavior, Animal Behavior, and Comparative Psychology

STUDIES IN THE PSYCHOLOGY OF TONE AND MUSIC*

From the Psychological Laboratory of Stanford University

By

PAUL R. FARNSWORTH

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PREFACE

This monograph contains a number of minor studies in the psychology of tone and music. They are relatively unrelated except as they represent certain of the attempts of the writer in the years 1930, 1931, and 1932 to work at the edges of the almost virgin field of musicology.

The Kwalwasser-Dykema music test study was financed by a Stanford University grant, a portion of which came from the Laura Spelman Rockefeller Memorial Foundation.

The tuning of the reed organ mentioned in Section VIII was accomplished with the aid of a mechanician in the laboratory of Professor Dayton C. Miller, of the Physics Department of Western Reserve University. The writer wishes to express his gratitude to Dr. Miller for his extreme kindness in this undertaking.

Acknowledgment is due the Misses A. L. Carmichael and Lillian Schuck, who aided in the collection of the data reported in Chapter IX; Mr. W. G. Campbell, who should be mentioned as having gathered the Kwalwasser-Dykema test data for the fifth and eighth grades; Mr. and Mrs. Malcolm Campbell, who have carried out many of the statistical computations necessary in the music test sections; Dr. Quinn McNemar, who has given statistical advice on several occasions; and Dr. Roy Langford, who planned the apparatus discussed in the appendix.

PAUL R. FARNSWORTH

STANFORD UNIVERSITY
CALIFORNIA

CONTENTS

I

A STUDY OF THE EXTENT TO WHICH SIMILAR TONAL ELEMENTS ARE ACCEPTED BY THREE DIFFERENT AGE GROUPS[1]

H. T. Moore (26) has shown that increasing acquaintance with tonal combinations which were formerly rated as bad or unpleasant tends to make them at least fairly acceptable. That is, there is an adjustment on the part of the person so that what was once rated as bad may on further acquaintance be listed as good. Moore found this to be true in the laboratory, where the acquaintance period was quite short.

Little is known experimentally concerning this problem when actual life conditions are involved, but it is supposed that the same rule holds as was found to be *true in the laboratory. For example, we find dyads* and chords in use today which harmonists of the past would not have allowed. No tonal preference tests, however, were given in the past, so we have nothing to compare with our present findings. In the future, of course, we can repeat the tests of today, but so far this remains a problem for a subsequent time.

If dangerous selective forces are adequately controlled there remains the possibility of testing people who differ in age and degree of musical sophistication. The Kwalwasser phonograph tests of melodic and har-

[1]Reported in part at the 1931 meetings of the Western Psychological Association.

monic sensitivity (19) lend themselves to such a problem. These phonograph records present melodic and harmonic phrases which are to be rated as good (liked) or bad (disliked). They are easy to administer, even in the fifth grade. The present writer had been making a study of these tests (7), so had on hand data from fifth and eighth grades of San José, California, and from psychology classes made up of sophomore Stanford students. There was some reason to believe that the grade schools were musically above average. Several surveys have shown the Stanford students to be slightly below average musically in comparison with other colleges, as there is no school of music attached.

The number of B (bad) ratings was tabulated for each test for the three groups.

TABLE 1

5th					8th			Stanford				
M	σ	N	D/σ_D	C in 100	M	σ	N	M	σ	N	D/σ_D	C in 100
Melodic sensitivity												
17.6	2.7	184	1.4	92	17.2	3.1	202	14.4	4.2	259	8.2	100
Harmonic Sensitivity												
15.8	4.1	184	2.0	98	15.0	3.9	202	11.7	4.6	259	8.4	100

In the melodic sensitivity test there is, then, a critical ratio of 1.4 between scores from fifth and eighth grades and a value of 8.2 between those from the eighth grade and the Stanford class. The corresponding values for the harmonic sensitivity test are 2.0 and 8.4. As can be seen by the chances in 100, there is a highly significant difference between the scores from the eighth grade and the Stanford class and a difference

of less significance between the fifth and eighth grades. As each test is 35 items long, the results for the harmony test indicate that more "goods" were listed than "bads" by all three groups. The same holds for melody except in the case of the fifth-grade ratings where the "bads" slightly outnumber the "goods."

The writer feels certain that these findings cannot be explained on the basis of musical selection. He also feels that the test reception was similar in the three groups. It is true that the younger subjects rendered a more nearly equal number of "good" and "bad" ballots than did the adults. However, the latter are more test wise, so, if there was an intentional attempt to even up the number of "bads" and "goods," one might expect the adults to do this.

We seem left with the conclusion that these data tend to bear out the theory that by increasing his acquaintance with music a person becomes more tolerant, and so is more prone to classify the elements as "good" or "acceptable."

II

MUSICAL TALENT AND THE LEFT HAND[2]

In 1923, Mrs. M. L. Sikes (38), a piano and organ teacher who had had 22 years of teaching experience, reported that she was able to foretell subsequent success in music by the simple device of observing which hand was favored in musical performance. According to her notions, if the left is more favored than the right the beginner will be more likely to succeed than when the reverse is true. For example, when her own small talented son was told to play with one hand he used the left. The two Sikes daughters, who are piano teachers, also hold to these ideas. According to Mrs. Sikes, this fondness for the use of the left hand has no connection with left-handedness.

Recently, in connection with a different problem, the present writer had occasion to send questionnaires to 300 of the leading music schools of the country. Returns were received from approximately 50 per cent of them. One question asked was the following:

> Some years ago a piano and organ teacher wrote an article in which she said that she could predict who were to be the most successful of her students by observing which hand they most used as beginners. Have you (or has any member of your staff) found any tendency for the more promising students to favor one hand? If so, which hand?

The vast majority of answerers claimed that there had been no such tendencies observed. On two returns

[2]Reported in part in *School Music*, 1932 (9).

were facetious remarks to the effect that it was to be hoped the lady in question had fully recovered by this time. On several papers, however, there was this helpful offering: The majority of beginning students of music are undoubtedly right-handed. This means that their right hands will more easily acquire the skilled behaviors necessary for successful performance. Most teachers and teaching systems do not sufficiently stress the extra drills needed by the left hands. Trouble is apt to develop later because of this defect. A student, however, who is more nearly ambidextrous does not need this extra stress. He is, therefore, at a considerable advantage over the average right-handed individual. Mrs. Sikes may have been observing these ambidextrous people. Since they were not definitely left-handed, she may have quite reasonably concluded that the matter was not connected with handedness.

No answer from the questionnaire explains the case of the small Sikes son. Here, however, the present writer will hazard a guess or two. (1) May it not be that Sikes, like many individuals, was perhaps unduly impressed by the lower piano notes, the ones with the greatest volume? These are struck by the fingers of the left hand. (2) In observing ambidextrous persons (who would employ their left hands more frequently than would right-handed persons) may not Mrs. Sikes have been so impressed by this greater frequency of left-hand performance that she neglected the perhaps equal number of right-hand activities? In our observations we notoriously neglect the negative instances.

A short time ago, Quinan (34, 35), a psychiatrist, reported that sinistrals (people who either throw balls with the left hands or have dominant left eyes)[3] are more often musicians than are dextrals (people who either throw balls with the right hands or have dominant right eyes). Quinan's thesis is that aesthetes are the more sinistral and sinistrals are the more psychotic. Thirty-two per cent of a group of 100 professional musicians were found to be sinistrals. When this percentage figure is compared with 26.1 for college undergraduates, one may very well question the significance of the difference.

Further data offered by Quinan are somewhat more convincing, as the differences between the percentages are statistically reliable. Of 590 college dextrals 23.8 per cent could "play on a piano or other instrument." For 225 sinistrals the comparable figure was 41.3. Of the dextral "musicians," 17.3 per cent preferred the violin while among the sinistrals the preference for this instrument was 26.7. This difference is interesting as it is difficult to find an instrument in which more left-hand skill is necessary.

Whether or not these speculations and apparent findings are accepted there remains the first point. Many teachers do not stress sufficiently the training of the left hand. An ambidextrous individual is, therefore, at a certain advantage as he proceeds towards his technical goals in music.

[3]Measured by asking the subject to sight a pistol at the tester.

III

A POSSIBLE SOCIAL FACTOR IN AESTHETIC RATINGS

In demonstrating to classes the various rating methods of recording preferences, the present writer has frequently presented material from phonograph records and Duo-Art rolls. He usually attempts to select an assortment of short pieces which will give a considerable range of preference. As a general rule, the class curves which are obtained are decidedly unimodal. However, when jazz compositions are considered in company with so-called "good" music, the former most generally give either bimodal distributions or flat curves which have no decided modes. The ratings for the jazz pieces are also prone to have the larger standard deviations. (At least these statements have proved true with Stanford students.)

A partial explanation for the differences seems to emerge when the subjects are carefully watched. The students appear to take the rating job quite seriously and, in the main, to have little difficulty in deciding where to mark the rating lines. On hearing the jazz, however, smiles frequently occur. These are often followed by audible laughter. The writer has observed that when one of these jazz pieces has just been played a number of subjects check or have hands in readiness to check the "very pleasant" portion of the lines, and then, at the outburst of laughter, erase the check marks and mark the lines nearer the "very

unpleasant" ends. This hesitant behavior seems much less frequent when other types of compositions are being considered.

This observation is, of course, subjective in the extreme. However, its scientific value might be considered as somewhat strengthened by two facts: (1) two of the writer's students who were acting as observers independently noted the phenomenon; and (2) the finding that there were more obvious erasures on the response lines on which jazz pieces had been rated (sufficient difference to be interesting, but not statistically reliable, D/σ_D, 2.0).

This matter might be of considerable importance in a study such as that of Trabue and Moler (43), in which a scale of "proper" responses to music was devised. The battery of pieces to be judged included both "approved" and jazz compositions.

Of course, it must be admitted that one cannot be absolutely certain that the laughter and erasures, or the laughter and the indecision, are causally related. Yet it would seem that if such a social factor should be operative it would be next to impossible to obtain a valid statement of the relative preferences toward jazz and so-called "good" music.

IV

A NOTE ON NOISE, DISSONANCE, AND PLEASURE

The acceptance of modern definitions of pleasure, agreeableness, pleasantness, and the like should alter most radically the attitudes of the harmonists and psychologists towards noise and dissonance.[4] Historically, these phenomena of music have been considered *per se* unpleasant. Even C. S. Myers (28), notwithstanding his experiences in the field of musical ethnology, is guilty of the following statements taken from his generally excellent book, *A Text-Book of Experimental Psychology:* (1) "Certainly in their purest form, noise and tone are fundamentally different experiences. The one is *unpleasant,*[5] rough, irregular, and difficult to analyse, the other is *pleasant,*[5] smooth, regular and relatively simple" (p. 26). (2) "There is hence a very strong tendency for octaves, and a diminishing tendency for fifths, fourths, thirds, and sixths, to produce an apparently single tone sensation. This blending or fusion of simultaneous tones corresponds in degree precisely with the recognized order of 'consonance' or *agreeableness,*[5] of the intervals in music. The octave is the most perfect consonance, of course excepting unison. Then follows the fifth, next the fourth, and lastly the major and minor thirds and sixths" (p. 46).

[4]See footnote 6.

[5]The present writer is responsible for the italics.

It is, of course, true that there are noises which are not desired in the majority of musical compositions. The same, however, is true of certain tones. There are other noises wanted for special effects. Each type of instrument has its own specific noises which help to make its timbre. To eliminate them is to alter or perhaps even to lose the peculiar pleasure one gets from listening to the instrument. Myers mentions the noise effect to be obtained "by pressing two long boards on the keys of the pianoforte, so as to strike a series of neighbouring black and white notes simultaneously" (p. 25). A similar procedure is now undertaken in ultra-modern music. It has been popularized by the composer Henry Cowell under the name "tone cluster." The board of Myers' experiment is replaced by the flat of the hand and the arm. Melodies and harmonies are produced out of these diatonic and chromatic clusters. To the uninitiated the affect *may* be one of unpleasantness. To one who has heard much of it, the affect is frequently one of extreme pleasure,[6] i. e., he wishes to hear more of it, says he is "thrilled" by it, "stimulated," etc. In fact, many listeners claim to have enjoyed such music the very first time they had the opportunity to hear it. The present writer has watched a number who gave overt evidence of so doing. Now, of course, the musically sophisticated may claim that tone clusters have no place in *real* music. But how can the pleasure be explained away?

[6]The psychological system of Woodworth (48) is probably typical of present-day theory. For him, "Pleasantness is the general set for keeping the situation as it is, unpleasantness is the general set for getting rid of the situation" (p. 285).

The point has been made that for Myers consonance is the equivalent of agreeableness. This view is most certainly an erroneous one although the fusion series did possibly agree with the order of pleasure in ancient times. But even in the Middle Ages the fifth was apparently the most preferred. Now, as many experiments demonstrate, the thirds have won, temporarily at least, in the preference race.

In consideration of these points, let us modernize our conceptions of the musical utility of noise and dissonance and of their relations to pleasure. They not only furnish contrasts to consonant music, but on occasion, even without the aid of the latter, they induce considerable pleasure.

V

CONCERNING CROSS RHYTHMS[7,8]

There are certain music compositions in which two different times are employed simultaneously. One hand, for example, may be forced to play 6 quarter notes while the other is playing 7.[9] Such occurrences are occasionally met with in accepted occidental music and are quite frequent in ultra-modern music. Henry Cowell's compositions may be taken to illustrate the latter. As examples of the former, MacDowell's *Tragic Sonata* and Chopin's *Nocturne in D♭* may be mentioned.

In the autumn of 1930 the present writer sent out a questionnaire to 300 of the leading music schools of the country. Returns were received from approximately 50 per cent of them. One portion of the questionnaire was phrased as follows:

---

[7]Reported in part at the 1931 meetings of the American Psychological Association and in *School Music* (10*a*).

[8]The term "cross rhythm" may not be the best term possible to express what the writer wishes to discuss. However, a perusal of musical dictionaries and discussions with musicians showed that there was only moderate uniformity of usage when items concerning time are involved. An analysis of the questionnaire returns indicated quite clearly that only two answerers were discussing what is mentioned in footnote 3.

[9]This is to be distinguished from conditions in which the *tones* are played simultaneously, but with different accents:

$$X\ x\ x\ X\ x\ x\ X\ x\ x\ X\ x\ x\ X$$
$$Y\ y\ y\ y\ Y\ y\ y\ y\ Y\ y\ y\ y\ Y$$

where X is an accented tone and x an unaccented one; Y a second accented tone and y the same unaccented.

For the past few months research work has been carried on at Stanford on the problems of the *simultaneous rendition of two different times. Since the question has arisen of the prevalence of time abilities, you will greatly oblige me if you answer these questions:*

1. Do you give special attention to the training of time abilities to the extent of teaching the student to to play in 2/4 time with one hand and 3/4 with the other? If so, what specific abilities are taught besides the ones mentioned? Underline your answers:
3/4 against 4/4; 2/4 against 5/4; 3/4 against 5/4; 2/4 against 7/4; 3/4 against 7/4; 5/4 against 7/4. Add other complexities if taught.

2. What percentage of musicians (teachers and performers) do you roughly estimate can beat out 2/4 time with one hand and 3/4 with the other?
3/4 against 4/4? 2/4 against 5/4? 3/4 against 5/4? 2/4 against 7/4? 3/4 against 7/4? 5/4 against 7/4?

The majority of the returns were in the form of letters. This rather successfully ruined any possibility of mathematical treatment of the answers so no definite information was obtained from Question 2. At least a few conclusions, largely of a qualitative nature, can be drawn from the answers to the first question:

1. The majority of the conservatories and schools of music from which returns were received offer no special training in the mastery of cross rhythms. It is assumed that the student will be able to develop the necessary techniques as they are needed.

2. A considerable number of institutions do train their students in the mastery of the simple cross rhythms, 2 against 3, 3 against 4, 2 against 5, etc. Several somewhat different methods are employed:

a. There is the kinaesthetic method in which the hands or fingers (or sometimes other members) are sep-

arately trained in two or more rhythms. The several members are then forced to beat out the times together. Jaques-Dalcroze and his system of eurhythmics (17) have made this method quite famous. In another article, W. F. Poynter and the writer (12) have described their study of the abilities of Arthur Hardcastle, a performer and composer of ultra-modern music. Hardcastle employed the kinaesthetic method with considerable accuracy and to some extent made use of the counting method which is discussed in the next paragraph.

b. In the counting method,[10] the subject counts to himself the least common multiple (or fraction of this) of the cross rhythms to be played. The example is given below of 2 against 3. One hand is played on the first, third, and fifth counts and the other on the first and fourth.

One hand		Other hand
▮	1	▮
	2	
▮	3	
	4	▮
▮	5	
	6	
▮	1	▮

When the multiple becomes large it can be split into parts. The example is given of 3 against 5. One hand is played on the first and fourth counts of the first group of 5, on the second and fifth counts of the second group, and on the third of the third group. The other hand is played on the first count of each group of 5.

[10] A recent popular account of the counting method can be found in the *Etude* (47).

x	1	x
	2	
	3	
x	4	
	5	
	—	
	1	x
x	2	
	3	
	4	
x	5	
	—	
	1	x
	2	
x	3	
	4	
	5	
	—	
x	1	x

When the playing of the ultra-modern composer, Henry Cowell, was analyzed it was found that he was employing this method.

c. There are various mixtures and modifications of these methods. For example, one teacher sets the metronome to beating one rhythm which he imitates by the *kinaesthetic method while he counts out a different* rhythm with the other hand. Another teacher attempts to coordinate two rhythms visually by means of positions on a line.

The present writer has developed a method which probably cannot be classified into any of the above three *groups. Blank player-piano rolls* are *punched* so that one temporal rate is presented by playing a succession of similar notes, say middle *c*'s, and a second rate by a succession of strikes on some other tone, say the *g* above. The subject listens to these, and attempts to accompany them on some other area of the keyboard. He gets an auditory Gestalt, as it were, of the notes.

By watching the stimulus keys as they are automatically depressed, he adds visual cues. As a variation in procedure he may even rest his fingers on the stimulus keys (having first regulated the lever which keeps the keys from depressing) and perceive the thumps.[11]

Henry Cowell, the composer, has recently developed the "rhythmicon" (with the aid of Theremin, the famous New York City electrical engineer). He based it on the writer's Gestalt idea, although his purpose was somewhat different. By holding down keys, pitches are *automatically* repeated at certain fixed rates of speed. For example, if the tone *c* is sounded twice in a unit of time, *g* will be sounded three times in the same unit. In this manner cross rhythms up to the complexity of 15 to 16 can be offered. The instrument can present any of these rhythms, or all at once if desired. The underlying principle is that of the photoelectric cell. Both the pitches and the absolute times can be regulated. Cowell has developed this instrument both for demonstrational purposes and as an accompaniment for certain of his piano and orchestral compositions.

Although no good quantitative study has or perhaps can be made of the relative efficiency of the methods of teaching cross rhythms, certain advantages and disadvantages might be suggested: (1) Since, in the kinaesthetic method, the subject has usually trained his hands in only two speeds, he may have difficulty in altering the relative speeds of his cross rhythms. This

[11]The player-piano rendition has been recorded phonographically with the loss of only the visual and tactual cues.

is not true when the counting method is employed. (2) The former would appear the better of the two when more than two cross rhythms are to be played at the same time. (3) An objection which a musician friend has raised to the Gestalt method rests in the possibility that the subject *may* perceive the cross rhythms as *one* complicated pattern. However, it is difficult to see how the other methods avoid this difficulty if it exists. (4) From his own experience and that of several students, the writer feels that the Gestalt method will be found to be the most efficient in terms of time to learn. (5) Training in *beating* out notes may not carry over to the rendition of *complicated music*. The writer has no answer to this objection at present.

VI

DYAD PREFERENCES IN TERMS OF SIGMA UNITS

A. Chromatic Dyads (Simultaneous)

In 1928 Guilford (15) proposed a method whereby preferences could be expressed in terms of sigma units. Several years later, T. L. Chichizola and the present writer (11) employed the procedure to ascertain preferences for small areas of color; more recently still, the present writer (10) has studied rectangle preferences by its aid. In this study, similar work has been done with tonal dyads.

Eighty-four Stanford students from classes in elementary psychology served as subjects. The stimuli were given by a Duo-Art reproducing piano set at loud intensity. Each stimulus had as its bass the *b* below middle *c*. The piano was tuned in equal temperament. Each dyad was sounded for about 2 seconds with a 2-second interval between. There was a 5-second interval between successive pairs. The directions were as follows:

> You are to hear 132 pairs of dyads (2 notes played together like a chord). After the rendition of a pair you are to decide which member is the more pleasant. If it is the first, record "1" in the space provided for it; if it is the second, record "2." If you don't know which you prefer, guess.

A rest of 10 minutes was allowed after the first 66 pairs had been presented.

Following the Guilford system, the stimuli were presented in a random order by the paired-comparisons method (as can be seen by the above paragraph). The 12 dyads were paired two ways so that each member would have an opportunity to be presented first.

The resultant rank order correlated almost perfectly (rho, .97) with the order given by Foster and Tinker (13). The former preference order correlated .66 with Stumpf's fusion series (39). In the color experiment mentioned above (11) the preferences ranged from +.80 to —.52 in terms of sigma units. In this study the values ranged from +.64 to —.95.

TABLE 2

CHROMATIC DYADS

Dyad name	Value*
Major 3rd	+.64
Minor 3rd	+.50
Minor 6th	+.36
Fourth	+.36
Octave	+.33
Major 6th	+.28
Tritone	+.20
Fifth	+.20
Major 2nd	—.33
Minor 7th	—.39
Major 7th	—.84
Minor 2nd	—.95

*The rank order does not *necessarily* mean that each dyad is preferred to the one *immediately* below it in the rank. Analyses of the data indicate that a preference over the neighbor immediately below in rank is *generally*, but not always, found to be the case.

We can only speculate on the preference ranks of the past. There may have been a time, as many theoreticians believe, when the octave, fourth, and fifth were the most preferred dyads. However, we can be more

certain of future rankings. In the writer's opinion some such experiment should be repeated from time to time to record possible preference changes. Tests of the preferences of musicians and other non-student groups should be made as well.

B. Chromatic Dyads (Successive)

The writer constructed a second roll which presented broken dyads, e.g., *b* and then *c vs. b* and then *d*. The melody sequence was invariably up. For example, the major third was always played as *b* and the next higher $d^{\sharp}$—never the reverse. Each tone was sounded for 1 second. There was a 1½-second period between tone members of a pair, and 2 seconds between the pairs to be compared. Five seconds elapsed between items. The dyads were presented in the order employed in Section A.

The rank-order correlation between the preferences for the broken and those for the simultaneously played was only .40. However, the preferences for these broken dyads correlated with the fusion series of Stumpf (39) with a value of .84. This apparently means that with such broken dyads fusion and preference have much more in common than they have where simultaneously rendered dyads are concerned (rho equaled .66 in the latter case).

C. Quarter-Tone Dyads

Although certain of the oriental peoples have long employed divisions of the octave considerably smaller than the semitone, occidental musicians have been slow

in accepting these small intervals. For some time, however, a number of the European conservatories (Prague, Budapest) have paid considerable attention to quarter-tones. The situation in America has been quite different. According to Grace Overmyer (30), "There are no records of fractional tone experiments in the United States earlier than 1924." This statement is decidedly in error, as in 1902 Max Meyer constructed a quarter-tone harmonium (the very instrument employed in the present study). The construction of the organ was followed shortly by two articles concerning quarter-tone music (23, 25) and a number of addresses before music groups. That quarter-tone music should be perfectly feasible[12] has been shown by Pratt (32, 33), who has written: "It is necessary to calculate . . . on the basis of the theory of probability, that smallest value of interval which will be perceived as different 100 per cent of the time. This value comes out just above 50 cents . . . It would, therefore, be theoretically feasible to double our present chromatic scale so that it would comprise twenty-four quarter-tones instead of twelve semitones."[13] In America no great enthusiasm *for quarter-tones* has followed Meyer's pioneering work.

At the suggestion of Meyer, the present writer was loaned the above-mentioned harmonium by the University of Missouri. The organ has two manuals formed by splitting each key in two. The upper man-

[12]Both Meyer and Baglioni (1) found that it was quite possible to enjoy these small intervals.

[13]See also Pratt's new book (33).

ual is tuned a quarter-tone above the lower. A more detailed description of the manual and its picture may be found in *The Musician's Arithmetic* (24). The instrument is now tuned in even temperament with middle *c* at 256 d.v.

Twenty-eight subjects from a class in experimental psychology served as subjects for a preference test. The method of paired comparisons was used, necessitating the tremendous number of 552 stimulus pairs [$n(n-1)$ where n equals the 24 quarter-tones]. Although the subjects appeared to be a very cooperative group, the stimuli were divided and given on four separate days to avoid undue fatigue and ennui. The pitch range was identical with that of Section A. The Guilford method of obtaining the preferences in terms of sigma

TABLE 3

QUARTER-TONE PREFERENCES

Range in Q. T.	Name	Value in sigma units
1		—.40
2	Minor second	—.38
3		—.45
4	Major second	—.17
5		+.06
6	Minor Third	+.44
7		+.12
8	Major third	+.64
9		+.08
10	Fourth	+.32
11		—.10
12	Tritone	+.19
13		—.18
14	Fifth	+.35
15		—.18
16	Minor sixth	+.33
17		—.03
18	Major sixth	+.58
19		—.20
20	Minor seventh	—.08
21		—.39
22	Major seventh	—.52
23		—.49
24	Octave	+.36

units was employed. It is interesting to note that the two lowest preference points occur on the chromatic scale. If the preference values are plotted and the resultant curve is smoothed, it will be seen considerably to resemble the curve for the chromatic-dyad preferences.

A rank correlation was run between the preference standing in Section A and the corresponding status of the chromatic dyads of this experiment. The value was found to be .85, a high value considering the presence of the quarter-tones, the different subjects, and the different timbre of the stimuli.

In 1928 Guthrie and Morrill[14] (16) studied, among other matters, the degree of pleasantness of certain intervals. The pitches extended from 395 v. s. to 615 v. s. at intervals of 5 v. s. They were rendered by Stern variators. The degree of pleasantness was judged by the percentage of 372 subjects that reported *the dyad in question pleasant. Now certain of these* intervals approximate rather inaccurately the quarter-tone dyads. Their relative standing has been correlated against the standing of the quarter-tones in the present study. The resultant rho was .75. This is surprisingly high in consideration of the differences in methodology and dyad intonations.

In 1927, Brues (3)[15] studied the fusion values of

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[14]In the Guthrie-Morrill study one finds the quarter-tones classified as "non-musical" intervals. *In consideration of oriental and* certain contemporary European music, this description should be abandoned. At least this is the opinion of the present writer.

[15]Same criticism of the use of the term "non-musical" as in Guthrie-Morrill experiment.

quarter-tones presented by Stern variators to a few well-trained observers. Fusion was defined as unitariness. Brues's fusion ranks from the 24 quarter-tones and the preference ranks of the present study correlated at .49. The size of this value indicates at least slight correspondence.

For many years Max Meyer has been a champion of the idea that habituation is not a very important factor in the formation of preferences (24). In this battle he has been decidedly on the minority side.[16] Now the present writer has no desire to enter this discussion with his data on quarter-tones, which appear to him as favoring neither of the camps. Of course, the fact that a few of the quarter-tones were far better received than were certain of the standard intervals might be taken to indicate that habituation was relatively unimportant. On the other hand, a number of the subjects claimed that the quarter-tones frequently called to mind closely related chromatic or diatonic intervals. This, it was believed, might have tended to affect the preference values. Were one testing an imaginary subject who had never heard chromatic or diatonic intervals, the quarter-tone preferences might have been smaller than was the case in this experiment.

Be all this theorizing as it may, the fact remains that the quarter-tones did receive relatively high preference values. In fact, certain of the non-musical subjects[17] expressed surprise that "such nice sounds" had so far contributed so little to occidental music.

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[16]For a recently published attack on Meyer's views see reference (31).

[17]Although "non-musical" in the sense that they knew little concerning musical theory, these subjects could distinguish the quarter-tones from their respective traditionally approved neighbors.

VII

THE PLAYER-PIANO AS A POSSIBLE AID IN TEACHING

With the aid of a punch, a hammer, and some blank player-piano rolls, a mechanically inclined music teacher can make almost any number of musical training devices. He needs merely to measure the proper distances on the rolls, and hammer away. The writer has constructed a number of such training aids which seem to him to have a certain amount of value. They are not tests in any strict or formal sense of the word. Their validities and reliabilities will probably be found to fluctuate somewhat in the various situations in which they might prove of use.

A. Interval Recognition

On the first quarter of the roll the 12 chromatic intervals appear twice in a confused order. They appear always as simultaneously played dyads with a bass on middle *c*. The second quarter of the roll is similar to the first except that the intervals occur as successively played (broken) dyads. The third section is similar to the first except that middle *c* is no longer the exclusive bass. The last section is similar to the third except that the intervals are played as successive dyads. In the various sections the letter notations are marked beside the stimulus holes on the roll.

The roll has at least the following uses: (1) The subject may listen to the intervals and watch the de-

pression of the piano keys. He may thus associate the sound of the intervals and the keys to be employed. (2) The subject may listen to the intervals and watch the letters as the roll passes by. This creates the possibility of associating the sound of the intervals and the corresponding letter notation. This use may be combined with use number 1. (3) The depressor action of the instrument may be locked so that the automatic playing of the keys is not visible. Then in the first half of the test the subject may place his fingers on the proper keys. In the last half of the test this procedure may prove to be quite difficult. Thus, at first the subject may recognize merely the intervals, and finger them as though they were in the octave of middle *c* with this as the bass. Later on, his skill may be sufficient to finger the notes he hears. (4) Instead of fingering the notes, the subject may write down the interval names or the bounding letters. (5) The roll may be employed in drilling letter names or symbols in the tonic sol-fa system. It may be played at any desired speed—slowly at first and then faster as the subject develops proficiency.

B. Chord Analysis

The roll starts with samples of the major chord in all three positions. Following these are samples of the three positions of the minor chord, and finally a sample of the whole tone chord. These are all bounded on the bass by middle *c*. The actual test begins at this point. First, the three positions of the major and minor chords appear twice and the whole

tone chord appears three times in a mixed order, all starting on the *e* above middle *c*. Fifteen chords are presented in all. The second half of the roll is precisely the same as the first except that here the chords are broken. The chord names are written on the roll in the proper places.

Among the possible uses for this roll are the following: (1) As a test of chord knowledge, the child may be told the names of the samples any desired number of times. Then the real test is taken, and the child's knowledge is ascertained. (2) It is a common procedure for the teacher to call off the names of the chords as he plays them and to teach the child to associate the chord names and the sounds or piano positions of the tones. If this roll is used, the child may read the correct names from the roll as it is being played. (3) He may also watch the automatic depression of the piano keys.

C. Control of Time

A series of rhythmic patterns is played over and over again. The subject accompanies the roll an octave higher. After a time the music ceases, but the roll continues moving, and the subject keeps on playing. After a certain number of repetitions he stops the instrument, opens the slides, and sees on the roll the extent of his time error. This is accomplished mechanically by figuring at what point on the roll a hole would have been punched if the instrument were still to accompany the player say 10 measures after the mechanical playing really did stop. A mark is placed on the

roll at this point with other marks at given distances on either side. (A weak point in the procedure is that the subject may vary in his rate of speed but be sufficiently fortunate to have his errors cancel. In this way he could arrive on time, as it were.) The function of this roll quite obviously is to strengthen the subject's time control.

D. Perception of Time Changes

This roll presents a series of tones at a constant speed. After a while the time accelerates or becomes slower. The subject is to stop the instrument when he first discovers the change, and to open the slides to view on the roll the degree of correctness of his responses. A check has been made on the roll to correspond with the point at which the time first changes.

The fact that the writer and one student became quite skilled at manipulating this roll may not necessarily mean that their time limens were altered. [See Seashore (37), on this.] The present writer does not wish to discuss this much-debated point. He readily grants that the utility of this "aid" is in question. A description of it is given mainly because it is a most amusing toy.

E. Resolutions

The diatonic scale in the key of *c* is played both ascending and descending. This is followed by a series of two-tone sequences in pairs, such as *c-d*, and *b-c*; *a-f*, and *d-g*. By this method, that of paired comparisons, each possible two-tone diatonic sequence is com-

pared with every other. The subjects are asked each time to judge which of the two sequences is the more "at rest" or "finished." The roll may be employed to drive home the resolutions deemed proper. This may be facilitated by marking the "correct" answers on the roll. Thus, the student may see the answer as he listens to the stimuli. He may also be tested from time to time.

From this discussion the reader should not conclude that the present writer feels that all music students should necessarily agree with the traditional harmonists in the matter of resolutions. In this day of atonic music, certain teachers may wish to keep their students from accepting too quickly the standards of the past. One's decision in this matter will probably rest on the particular philosophy of music adopted.

F. Differently Accented but Simultaneously Rendered Tones

It was previously pointed out that one occasionally meets the phenomenon of differently accented but simultaneously rendered tones. Let the following be an example:

$$\begin{array}{l} X\ x\ x\ X\ x\ x\ X\ x\ x\ X\ x\ x\ X \\ Y\ y\ y\ y\ Y\ y\ y\ y\ Y\ y\ y\ y\ Y \end{array}$$

in which X is an accented tone, x the same tone unaccented, Y a different accented tone, and y the same tone unaccented. The methods mentioned in Chapter V might conceivably serve for this problem although their relative efficacies are not known.

The present writer has constructed a roll which presents the complexities 2 against 3, 3 against 4, and 2, 3, and 4 against 5. Such a tool can be easily made from a Duo-Art roll by virtue of the theme control this mechanical player possesses. This Gestalt method impresses the writer as worth while. However, he realizes that, in the last analysis, trained music teachers must decide on its worth.

G. Playing Rolls Backward

It is a simple matter to rewind a roll so that the music is presented from the end to the beginning instead of in the more natural order. Such a procedure has its values. The unusual effects obtained by backward renditions act as exaggerators of normal effects much as abnormal behavior caricatures the normal. (Phonograph records can also be played backward by simple alterations in the wiring of the phonograph mechanism. Phenomena similar to those gotten from the rolls can be obtained. The use of the backward-playing phonograph might also prove important in studying speech).

H. Mirror Inversions

Another trick possible with a player-piano roll is that of turning around the roll as it is inserted in its slot so that the soprano portions are played in the bass and the bass in the soprano. The effect is as if a mirror inversion of the notes had been made. At the moment the author can imagine no educational function for this procedure, but offers it in the hope that

some noble use may eventuate. It is possible to play the roll backward and invert it at the same time. When misusing the roll care must be taken to keep it from rewinding. This it is likely to do as the rewind slot may on occasion be activated by holes whose functions are quite different in the normal performance. Quite annoying is the fact that after a rendition the roll must either be rewound by hand or be pulled from the lower roll rack, be replaced in its normal rewind position, and be rewound while the motor button is being forcibly held out.

I. A Proof That the Engineer Should Take into Account His Subjects' Responses

It is frequently convenient for the psychologist to have at hand illustrations proving the fact that the engineer should attend to psychological responses as much as to the physical stimuli. At least he should not neglect the response side of his problems. Duo-Art Demonstration Roll S-2935 furnishes such an illustration.

This roll was made to display the Duo-Art's many wonders. Among these is the alleged superiority of its loudness controls over those of its competitors. It offers 16 different intensities of hammer strokes, considerably more than does either of its two chief rivals. These intensities are presented at the beginning of the demonstration roll by the appearance of 3 tones of number 1 intensity, then 3 of number 2 intensity, 3 of number 3, etc.

It was decided to ascertain by the use of this roll the

relative perceptibilities of these intensity stimuli, to learn, in fact, whether or not there were 16 equally perceptible loudnesses. To do this it was necessary to prevent the subjects (two groups, one of 33 and another of 45 from classes in elementary psychology) from knowing that each set of three tones was at a different intensity. The piano had just been overhauled by a Duo-Art expert and declared to be as good as new.

The directions were as follows:

> You will hear a series of 48 tones grouped in threes. Each group of 3 may or may not differ in loudness from the preceding. If it seems louder than the preceding group put a check mark opposite it in the proper space on the blank provided you.

The experimenter played the roll at "time 30," and at "normal" intensity. To keep the subjects from losing their places he held up a series of numbered cards, a number 1 while the first group was being played, a number 2 while the second set was being rendered, etc. When the subjects were told at the end of the experimental period that there had been a change in physical intensity with each set of 3 tones they expressed considerable surprise.

The checks were tabulated and found to correlate at .45 (rho) for the two groups. Although this agreement is not high, there was almost perfect correspondence for the sequence of the periods of greater and lesser perceptibility. With only one exception an intensity value of greater perceptibility was followed by one of lesser, and this, in turn, by one of greater percepti-

bility. Thus about one-half the intensities were well perceived. This demonstration bears out a conclusion made by Whipple in 1928 (45) to the effect that not all the 16 Duo-Art intensities were equally important.

VIII

FURTHER DATA CONCERNING THE LIPPS-MEYER LAW

The writer's proposed modification of the Lipps-Meyer Law (6) which appeared in 1926 read as follows: "The ratio-symbols 2, 3, 5, and 7, when employed as endings, display repose effects in the inverse order of their size. Specific training can markedly change this order." These conclusions were based on a series of studies in which the stimuli were derived from a specially constructed reed organ tuned in equal temperament. On several occasions since that time the writer has been asked to attempt a similar study with just intonation.[18] Recently, with the aid of Professor Dayton C. Miller of the Physics Department of Western Reserve University, the reed organ was retuned in just intonation.

Three groups of approximately 40 each, drawn from courses in elementary psychology, served as subjects. Procedures almost precisely similar to those of the earlier study were employed. However, instead of giving the sequences on three successive days (to minimize the factor of falling inflection) they were offered in reduced number (54 in place of the original number 90) on the same day but with pauses of 10 minutes' duration between the three sets of sequences. The pitches involved were 168, 240, 288, 336, and 480 cycles

[18]The most recent study of ending preferences, that by Zener (49), employed equal temperament.

for the first set of sequences; 180, 216, 252, 360, and 432 cycles for the second set; and 192, 224, 320, 384, and 448 cycles for the third. The order of rendition was not the same for all groups of subjects. For the first group a falling inflection was used. With the second a rising inflection occurred. In the experiment with the third group of subjects the order was falling, then rising inflection.

In the writer's 1926 study (6) the relative preferences for a class of 40 were: ratio-symbol 3, 40%; 5, 34%; and 7, 26%. Assuming that, if chance (statistical sense) alone had operated, the values would all have been 33, it can be seen by the method of X^2 that there are only 20 some chances in 100 that subsequent experiments would not give deviations from 33 as great as or greater than were obtained. In the first of the present experiments the percentages were: ratio-symbol 3, 32%; 5, 46%; 7, 22% (1 or 2 chances in 100). In the second they were: ratio-symbol 3, 43%; 5, 24%; 7, 33% (approximately 7). In the last experiment the values were: ratio-symbol 3, 28%; 5, 35%; 7, 37% (50 some chances, so no significant deviation from chance).

It is quite obvious that some factor (or factors) has (have) caused these data to be different from those obtained with equal temperament. In the writer's opinion the change was brought about by the change in tuning. This view is somewhat substantiated by the behavior of the subjects. These latter commented most vigorously about the mistuning of the stimuli. Of course, the tones were not mistuned in the historic

sense of the term; yet they were frequently quite sharp or flat to those subjects who had good discriminatory ability, and who were not familiar with just intonation. Moran and Pratt (27) have stated that the present writer in an earlier article accepted Max Meyer's dictum to the effect that the tempered scale functions exactly as does the natural scale. This assumption is at least in part erroneous, as nothing was said about "functioning exactly." However, it must be admitted that the present writer did not at that time anticipate the serious confusion which just intonation could cause in the matter of ending preferences.

An examination of the stimuli to see their deviations from equal temperament in terms of cents (a cent is a twelve-hundredth of an octave) will probably prove of value. Table 4 reads as follows: In the case of

TABLE 4

STIMULI SEQUENCES AND DEVIATIONS FROM EQUAL TEMPERAMENT

First experiment	
7 down to 3 (+33)	down to 5 (—16, +17)
3 down to 5 (—16)	down to 7 (—17, —33)
5 down to 7 (—17)	down to 3 (+33, +16)
Second experiment	
5 up to 3 (+16)	up to 7 (—33, —17)
3 up to 7 (—33)	up to 5 (+17, —16)
7 up to 5 (+17)	up to 3 (+16, +33)
Third experiment	
3 down to 5 (—16)	up to 7 (—17, —33)
7 down to 3 (+33)	up to 5 (—16, +17)
5 down to 7 (—17)	up to 3 (+33, +16)

the first sequence, the 3 is 33 cents sharper than its equally tempered equivalent, if the ratio-symbol 7 is taken as a point of orientation. The 5 is 16 cents flat if 3 is accepted as the orientation point, but 17 cents

sharp if the 7 is maintained as the point of comparison, etc. (If the ratio-symbol 2 could possibly be kept in mind, the ratio-symbol 3 would always be 2 cents out of line, the 5 would be 14 cents, and the 7 would be 31 cents from the position of the corresponding equally tempered equivalent.)

In the second experiment, in which rising inflection was the rule, the occurrences of mistunings are different. In the sequence 5 to 3 to 7 the 3 is 16 cents sharp and the 7, 33 cents flat, etc., etc.

In a review of studies on feeling and emotion, Washburn (44) has said: "To account for ending preferences Farnsworth says that we must assume two principles, the tonic principle (human beings prefer the tonic as a melodic ending), and the habit principle . . . The reviewer would ask why the tonic principle is not a special case of the habit principle, since nature familiarizes us with the association of a tone and its overtone intervals?" It would seem that Washburn has failed to realize that her nature suggestion is in truth an hypothesis, on a par with Pratt's ideas of intrinsic qualities (33) and Meyer's theories concerning the functioning of the nervous system (24). The present writer in his earlier article was stating his discovery that training of a fairly obvious sort could be one element in the establishment of ending preferences. Although there is evidence that the effect is usually fully established by age 14 (35*a*), there yet remains to be explained the origin of tonic behavior itself. This *may* eventually be reduced to some habit phenomenon, but again the issue may not be so solved when adequate data are at hand.

The writer will not attempt to explain the preferences as found in the present experiment. He merely wishes to make the point that with such apparent mistuning it is little wonder that the results are so different from those obtained with equal temperament. Were he to restate the Lipps-Meyer Law he would do so as follows: "The equally tempered approximations of the ratio-symbols 2, 3, 5, and 7, when employed as endings, display repose effects in the inverse order of their size. Specific training can markedly change this order. This law holds for American college students when simple 2-, 3-, or 4-tone sequences near the center of the piano range are employed. Nothing, however, is definitely known concerning the conditions responsible for this effect, the cultural groups for whom it holds, or the limits of the tonal range in which it exists."

IX

FURTHER STUDIES OF THE SEASHORE AND KWALWASSER BATTERIES

A. The Gaw Modifications of the Seashore Sense of Time and Tonal Memory Tests[10]

Gaw (14) has pointed out that the Seashore Sense of Time and Tonal Memory tests (36) are considerably too difficult for fifth-graders. She has, therefore, proposed modifications of each. Her new time test includes face A of the old record with the last column of stimuli of face B added. The test is given twice, and thus provides 120 stimuli. In this way the columns with .09-second differences are the most difficult offered. The memory test is modified by omitting the five- and six-span columns of the old test and by twice repeating the remaining portions of the record. This procedure gives a total of 90 stimuli. In the Gaw article, percentiles are offered based on 53 fifth-graders who had taken the new time test and 141 fifth and sixth-graders who had taken the tonal memory test.

The present writer decided to gather more complete information concerning these modifications of the Seashore records. One hundred thirty fifth-graders from the schools of Palo Alto, California, were examined.

The two tests were found to intercorrelate to the extent of $.37 \pm .05$. The odd-even reliability of the

[10]Reported in part at the 1931 meetings of the Western Psychological Association.

memory test was .85±.02; the value for the time test was .76±.03.[20] These coefficients are considerably

TABLE 5

TONAL MEMORY

Percentage correct	Rank	Percentage correct	Rank
98+	100	62	42
97	99	61	40
96	98	60	39
95	96	59	37
94	95	58	34
93	92	57	33
92	89	56	32
91	87	55	31
90	84	54	31
89	84	53	30
88	83	52	28
87	81	51	25
86	80	50	23
85	79	49	23
84	79	48	22
83	78	47	21
82	75	46	20
81	74	45	19
80	73	44	17
79	72	43	15
78	71	42	14
77	70	41	13
76	68	40	12
75	66	39	11
74	64	38	9
73	62	37	8
72	59	36	8
71	57	35	7
70	56	34	6
69	54	33	5
68	53	32	5
67	50	31	4
66	49	30	3
65	48	29	3
64	47	28	3
63	45	27	3
		26	2
		25	2
		24	1

[20]Raised by the Spearman-Brown formula, these reliabilities become .92 and .86.

higher than those found by the writer in a study of the original forms of these tests (7). The values then were of the magnitudes .74±.02 for the memory test and .58±.03 for the time. McCarthy (22) has reported a value of .75 for the old memory test. In the present study, approximate percentiles were developed for both tests.

TABLE 6

SENSE OF TIME

Percentage correct	Rank	Percentage correct	Rank
96+	100	74	40
95	99	73	37
94	99	72	33
93	98	71	30
92	97	70	27
91	97	69	24
90	96	68	23
89	94	67	21
88	90	66	19
87	87	65	15
86	85	64	12
85	81	63	11
84	80	62	10
83	77	61	10
82	71	60	9
81	65	59	8
80	58	58	7
79	56	57	5
78	50	56	4
77	46	55	3
76	44	54	2
75	42	53	1

An inspection of Tables 5 and 6 and the tables offered by Gaw (14) indicates that the Gaw modifications are somewhat too easy for fifth-graders. Their length (a considerable increase over the old forms) is such that fifth-graders are apt to become fatigued. However, with their increased reliabilities they are undoubtedly improvements over the older forms.

B. SEASHORE SENSE OF RHYTHM PERCENTILES

In an earlier monograph (7) in which the Seashore music tests were studied, the present writer found that the adult norms obtained at Stanford agreed quite well with the norms constructed at Iowa (36). This statement held for the earlier tests. The most recently constructed, however, the test of rhythm discrimination, violated the generalization in that the Stanford median and mean scores approximated 84 and 77 percentiles instead of 50 percentile on the Iowa norms. Strangely enough, a recent check by R. C. Larson (21) found median scores which approximated 35 percentile.

The present writer does not wish to postulate theories concerning the reasons for these discrepancies. He merely feels that, inasmuch as, quarter after quarter, he has found Stanford sophomores giving higher mean scores than they should according to the accepted Seashore norms, he should employ his own percentiles. It

TABLE 7
212 STANFORD SUBJECTS ON THE RHYTHM TEST

Percentage correct	Rank
96+	100
94	99
92	97
90	95
88	90
86	83
84	75
82	65
80	50
78	36
76	27
74	17
72	10
70	3
68	1

is interesting to note that Broom (2) also found California students scoring more highly than was expected on the rhythm test.

G. Percentiles for Kwalwasser Melodic and Harmonic Sensitivity Tests, Victor 35573

The writer has previously demonstrated (7) that for Stanford subjects the norms offered by Kwalwasser (19) are inadequate. This finding was to have been expected since Kwalwasser made no allowance for age in the construction of his norms. The writer, therefore, presents a sample of his Stanford figures in the hope that it may give a better picture of the college level than do the norms offered by Kwalwasser.

TABLE 8

200 Stanford Subjects on the Sensitivity Tests

Melodic		Harmonic	
Percentage correct	Rank	Percentage correct	Rank
33+	100	33+	100
32	98	32	99
31	97	31	98
30	95	30	98
29	88	29	95
28	79	28	93
27	66	27	86
26	52	26	74
25	33	25	60
24	25	24	49
23	17	23	35
22	11	22	20
21	9	21	14
20	7	20	8
19	3	19	4
18	2	18	1
17	1		

X

THE KWALWASSER-DYKEMA MUSIC TESTS AS PSYCHOLOGICAL TOOLS[21]

A. The Problem

A short time ago the present writer made a study of the Seashore and Kwalwasser music test batteries (7). The major point of interest rested in their utility as psychological tools. A somewhat similar study of the Kwalwasser-Dykema battery (20) would appear to be even more urgent as little statistical information concerning it is available.

B. A Description of the Tests

Ten tests are included in this battery. Each member occupies one side of a doubled-faced ten-inch record. The tests are supposed to measure capacities and abilities, the effects of training being more apparent in certain of them than in others. The set can be carried in a small case which occupies little space.

The *tonal memory* test consists of 25 pairs of patterns which range from 4 to 9 notes each in length. The patterns are played twice, either in exactly the same or in changed form. The subject responds by the words "same" or "different." (See Section C.)

The test of *quality discrimination* includes 30 ele-

[21]The Kwalwasser-Dykema battery will be referred to hereafter as the K-D tests. This battery should be distinguished from an earlier record made by Kwalwasser which purports to test melodic and harmonic sensitivity (19). For a critical study of this latter record see reference 7.

ments, each of which is composed of two notes played on one instrument and immediately repeated either on the same or on a different type of instrument. The subject's response is "same" or "different." The instruments whose playings are repeated are the trombone, violin, oboe, English horn, French horn, flute, muted viola, clarinet, 'cello, viola, muted trumpet, bassoon, tuba, and piano. When the second renditions are not given by the same instruments, the following are paired: clarinet and trombone, clarinet and oboe, 'cello and bassoon, 'cello and violin, 'cello and trombone, 'cello and viola, viola and violin, viola and muted trumpet, muted viola and muted violin, trumpet and French horn, trumpet and flute, muted trumpet and muted trombone, muted trumpet and English horn, piano and celeste, violin and oboe, and flute and French horn.

The measure of *intensity discrimination* is constructed in a manner quite similar to that of Seashore's intensity test. (See Section C.) Thirty tones and chords are repeated at different intensities. The subject judges whether the second of a pair is weaker or stronger than the first. This record is taken from a Duo-Art reproduction which allows a number of different degrees of loudness.

Tonal movement refers to the ability of a subject to indicate orthodox musical endings. Each test element consists of four unresolved notes. The subject decides whether the tone which would give the best possible resolution (according to the musical theorists) is higher (up) than the last tone given or lower

(down). The actual tone is not requested, merely the direction of the proposed completion tone. There are 30 items.

The measure of *time discrimination* has also been made from a Duo-Art player-piano roll. The tones are compared as to duration with the tones preceding and following (judged "same" or "different"). The temporal variations range from .03 to .30 second. The stimuli (25 items) are presented in a random order. (See Section C.)

The test of *rhythm discrimination* contains 25 items. Each item is composed of two measures which form a rhythmic pattern. This is repeated either in the same or in different form. (See Section C.)

In the test of *pitch discrimination* there appear 40 items. A tone (either 500 or 1000 d.v.) is sustained for approximately 3 seconds. It either retains its pitch perfectly (rated as "same"), or else rises or falls anywhere from .6 to 50 d.v., and then returns to the starting pitch (rated as "different"). (See Section C.)

The test of *melodic taste* attempts to measure "on the basis of general musical appeal sensitiveness to structure, balance, and phrase compatability." The items (10 or 20)[22] consist of two melodies of two phrases each. The first, or opening, phrases of each melody are identical. The second, or concluding, phrases are unlike. These latter are to be compared for their suitability as concluding phrases.

In the test of *pitch imagery* 25 measures of notes

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[22]The *20-* (not the *10-*) item test was studied in this monograph.

are played to the subject. He is to compare each measure with what is on the printed blank which has previously been distributed to him. All of the chromatic characters are present in the music. The responses are "same" and "different."

The *rhythm imagery* test is similar in almost every way to that of pitch imagery with the exception that heard and seen rhythmic patterns are to be compared instead of pitch patterns.

G. Relations between Corresponding Tests in Kwalwasser-Dykema and Seashore Batteries[23] [24]

The Kwalwasser-Dykema and Seashore (36) batteries overlap to the extent of presenting five tests each which purport to measure similar capacities and abilities. The test fields include pitch discrimination, differences in rhythmic patterns, intensity discrimination, memory for tones, and time discrimination.

The pitch tests have quite dissimilar constructions. In the K-D measure a tone is sustained for approximately 3 seconds. It either retains its pitch perfectly or else starts at 500 d.v. (or 1000 d.v.), rises or falls anywhere from .6 d.v. to 50 d.v., and then returns to the starting pitch. When the former event occurs, the subject's response is "same"; for the latter the answer is "different." There are 40 items arranged in ran-

[23]When nothing is stated to the contrary it is to be assumed that the records were played on an old-style phonograph.

[24]Reported at the 1931 meeting of the Western Psychological Association.

dom order. The 100 items of the Seashore test, on the other hand, are arranged in a very definite sequence. In each instance two tones are played twice. The second is recorded as being "higher" or "lower" than the first. (The actual differences range from ½ to 30 d.v.)

The rhythm tests are alike in that the subject's judgments are recorded as "same" or "different." The K-D test employs tones and the Seashore, clicks. The former test is only one-half the length of the latter.

The intensity tests have much the same construction. Several differences, however, may be pointed out: (1) The K-D test employs piano tones while the Seashore test uses the audiometer; (2) in the former test there is a random order of difficulty while in the latter there is a regular progression in difficulty (10 easy items, then 10 less easy, etc.); (3) while the K-D test contains only 30 items, the Seashore possesses 100.

The Seashore memory test attempts to measure the subject's immediate memory for changed notes. That is, the changed note itself must be designated. From 2 to 6 notes are repeated in changed form. In the K-D test the subject is required merely to state whether the repetitions are similar or dissimilar. The patterns vary from 4 to 9 tones each. The Seashore employs flute tones; the K-D uses the piano. The K-D is one-half the length of the Seashore.

The K-D time test presents intervals of filled time. Piano tones are compared as to duration with the tones preceding and following (judged "same" or "different"). The temporal variations range from .03 sec-

ond to .30 second. The stimuli (25 items) are presented in a random order. The Seashore test, on the other hand, presents intervals of *empty* time. Each item (there are 100 such) is composed of two temporal intervals. The second is to be judged relative to the first. The temporal variations range from .02 second to .20 second. A set order is maintained.

Correlations between the pairs of similar tests were run on Stanford sophomore subjects.[28] These coefficients were of the following magnitudes: pitch, .17±.05; rhythm, .24±.07; intensity, .03±.05; tonal memory, .62±.04; and time, .38±.06. Whether or not one believes in applying the formula for correction for attenuation, the fact remains that, with the exception of the tests of tonal memory, these records are not measuring at all perfectly the same behavior variables.[29]

These findings have been verified by Tilson (41, 42) who has worked with college students enrolled in a music supervisors' course. The Tilson procedure, however, was somewhat unusual in that the pitch tests were presented three times (on successive days) and the other measures twice each. The highest scores only were recorded. Tilson has argued that in this way the students' physiological limits are more likely reached.

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[28]In this and succeeding sections the adult subjects were all taken from courses in elementary psychology. The fifth- and eighth-grade subjects were from schools in San José, California.

[29]If the present writer's Seashore reliabilities (7) and the stepped-up odd-even values for the K-D (reported in a subsequent section) are employed in corrections for attenuation, the coefficients become .23, .46, .04, .82, and .58, listed in the order given above.

The present writer is inclined to believe, however, that this method allows chance variations toward higher scores to be favored over similar variations toward lower scores. Be this as it may, the values are somewhat similar to those obtained at Stanford. They are pitch, .14±.07; rhythm, .22±.07; intensity, —.12±.08; tonal memory, .32±.07; and time, .40±.06.

Another and later study by Whitley (46) gives higher values (pitch, .49±.04; rhythm, .43±.05; intensity, .38±.05; tonal memory, .71±.03; and time, .55±.04). For Whitley, as for the present writer, the two tonal memory tests gave the highest of the intercorrelations.

Drake (5) has compared the tonal movement test with several members of the Seashore battery. His values were found to be: pitch, .48±.04; rhythm, .12±.05; intensity, .21±.05; time, .21±.05; memory, .50±.04. With age, intelligence, and training partialed out, the values are .42, .08, .15, .19, .47.

In a study of eighth-grade school children, Sanderson (35*b*) found correlations between corresponding K-D and Seashore tests as follows: pitch, .43±.02; intensity, .27±.02; tonal memory, .48±.02.

D. Reliabilities

Figured from the standpoint of odd-even item correlations the values for adults are very small, with the tonal movement reliability as the only promising coefficient. Judged from the retest side, the tonal

memory test is the best of the battery.[27 28] It is difficult to ascertain which of the two methods is the better one to employ with this battery. The present writer somewhat favors the retest values, as the memory carry-over appears to be extremely small, and the tests seem too brief for the split-half method properly to be employed.

TABLE 9

RELIABILITIES OF TESTS*†

Test	Odd-even	Stepped-up values	Retest
Tonal memory	.45±.05	.63	.73±.04
Quality	.39±.06	.56	.53±.06
Intensity	.43±.05	.60	—.10±.09
Tonal movement	.74±.03	.85	.55±.06
Time	.46±.05	.63	.42±.08
Rhythm discrimination	.16±.07	.28	.21±.09
Pitch discrimination	.46±.05	.63	—.05±.09
Melodic taste	.16±.07	.28	.53±.06
Pitch imagery	.20±.07	.33	.42±.06
Rhythm imagery	.11±.07	.20	.40±.06

*Whitley (46) has also figured reliabilities for these tests by the split-half method. Her values, while a bit lower than those of the present writer, resemble the latter markedly. They are: tonal memory, .46±.05; quality, .23±.06; intensity, .23±.06; tonal movement, .67±.03; time, .33±.05; rhythm, .23±.06; pitch, .27±.06; melodic taste, .19±.06.

†A study by Drake (5) has just come to the writer's attention. The reliabilities of the K-D tests were figured by correlating the upper five rows against the lower five. With the majority of tests two sets of subjects were employed, musical and non-musical. The results for the groups are: quality, .50±.07, .25±.05; melodic taste, .44±.07, .25±.05; pitch, .25±.09; tonal memory, .38±.08, .40±.04; tonal movement, .74±.04, .58±.03; rhythm, .11±.05 (not stepped up).

Kelley (18) has given a formula (number 147) for obtaining the reliability of a battery if the reliabilities of and the intercorrelations between the several constituent members are known. If the present writer's

[27]One and one-half months elapsed between testing periods.
[28]See section on norms.

TABLE 10
PANATROPE DATA

Test	r_{1oe}*	r_{1oe} Stepped up	r_{2oe}	r_{2oe} Stepped up	$r_{1\&2oe}$	$r_{1\&2oe}$ Stepped up
Tonal memory	.41±.05	.58	.42±.04	.59	.51±.04	.68
Quality	.28±.05	.44	.32±.05	.48	.37±.05	.54
Intensity	.37±.05	.54	.23±.05	.37	.36±.05	.53
Tonal movement	.68±.05	.81	.74±.04	.85	.64±.05	.78
Time	.43±.04	.60	.47±.04	.64	.51±.04	.68
Rhythm discrimination	.34±.08	.51	.18±.08	.31	.52±.06	.68
Pitch discrimination	.10±.09	.18	.00±.09	.00	.06±.09	.11
Melodic taste	.00±.05	.00				
Pitch imagery	.22±.05	.36	.36±.05	.53	.32±.05	.48
Rhythm imagery	.35±.08	.52	.33±.08	.50	.44±.07	.61

* r_{1oe} refers to the odd-even correlations of the first rendition; r_{2oe}, to the odd-even correlation of the second rendition; $r_{1\&2oe}$ to the odd-even correlations of the doubled tests treated as if they constituted a single test.

data are assumed, r equals .77. This is to be compared with the value of .89 found for the Seashore battery (7).

The data of Table 9 were gathered with the aid of a non-electric phonograph. At later dates, in an attempt to raise reliabilities, new data were gathered on a Brunswick panatrope. The tests were given, and then immediately repeated. The subjects were led to believe that the repeated sections were new forms of the tests. The papers were accordingly folded to prevent copying. The test of melodic taste was not repeated as the normal 20-items test is really a retest. At various times during the testing periods many of the subjects probably decided that they were hearing mere retests. How important an effect this had on the results it is impossible to state.

TABLE 11

ODD-EVEN RELIABILITIES* †

Test	5th grade	Stepped up	8th grade	Stepped up
Tonal memory	.39±.04	.56	.09±.05	.16
Quality discrimination	.39±.04	.56	.46±.04	.63
Intensity discrimination	.48±.04	.65	.75±.02	.86
Tonal movement	.79±.02	.88	.44±.04	.61
Time discrimination	.39±.04	.56	.47±.04	.64
Rhythm discrimination	.38±.04	.55	.38±.04	.55
Pitch discrimination	.35±.04	.52	.28±.05	.44
Melodic taste	.22±.05	.36	.02±.05	.04
Pitch imagery	.01±.05	.02	—.83±.02	—.91
Rhythm imagery	.45±.04	.62	.42±.04	.59

*Whitley (46) has also gathered data from children of the grade schools. Her figures are not given here as her grades are not comparable to the ones studied by the present writer. They agree, however, in revealing low reliabilities.

†Since this monograph went to press the Sanderson article (35b) has appeared. It reports retest reliabilities which are very low.

On the whole these changes in procedure did not markedly aid the reliabilities of these tests.

The data obtained from children of San José, California, are given below. The reliabilities are very poor, in the main. This is especially true of the pitch imagery test, which is rather difficult for school children who have had little formal musical training.

In letters to Dr. R. M. Mosher of San José (California) State College and to the present writer, Kwalwasser has mentioned reliability figures computed by a Mr. Bushnell Bowman. These are retests conducted on 150 subjects, 120 of them being elementary- and secondary-school children and the remainder university students. The values are naturally considerably higher than those the present writer has obtained from much narrower age ranges.

TABLE 12

BOWMAN RELIABILITIES

Test	r P.E.
Tonal memory	.72±.03
Quality	.65±.03
Intensity	.63±.03
Tonal movement	.83±.02
Time	.53±.04
Rhythm discrimination	.47±.04
Pitch discrimination	.65±.03
Melodic taste	.35±.05
Pitch imagery	.70±.03
Rhythm imagery	.58±.04

The only possible conclusion to be made on the subject of reliabilities would seem to be that, with the possible exception of the test of tonal movement, the Kwalwasser-Dykema tests are too unreliable for individual prognostication.

TABLE 13
INTERCORRELATIONS*

	Pitch	Intensity	Time	Rhythm	Pitch imagery	Rhythm imagery	Memory	Tonal movement	Quality
Intensity	.13±.07 .18±.05 .07±.05								
Time	.05±.05 .33±.04 .15±.05	—.01±.06 .19±.05 .20±.05							
Rhythm	.09±.05 .30±.05 .16±.05	—.07±.06 .08±.05 .30±.05	.02±.05 .23±.05 .51±.05						
Pitch imagery	.12±.07 .21±.05 .09±.05	.29±.06 .00±.05 .05±.05	.51±.07 .14±.05 .07±.05	—.01±.08 .11±.05 .08±.05					
Rhythm imagery	.01±.07 .29±.05 .24±.05	.05±.07 .14±.05 .25±.05	.31±.07 .28±.05 .17±.05	.01±.08 .24±.05 .20±.05	—.07±.07 .24±.05 .04±.05				
Memory	.13±.06 .39±.04 .12±.05	.06±.07 .05±.05 .24±.05	.10±.07 .23±.05 .05±.05	.11±.07 .22±.05 .35±.04	.34±.06 .24±.05 .03±.05	.15±.07 .16±.05 .13±.05			
Tonal movement	—.05±.07 .30±.05 —.05±.05	—.16±.06 .00±.05 .01±.05	.16±.07 .04±.05 .00±.05	.16±.07 .15±.05 .13±.05	.37±.06 .25±.05 .09±.05	.37±.06 .20±.05 .17±.05	.41±.06 .33±.04 .08±.05		
Quality	.05±.06 .23±.05 .12±.05	.04±.07 .06±.05 .20±.05	.09±.08 .30±.05 .06±.05	.08±.08 .32±.04 .53±.04	.16±.07 .01±.05 .02±.05	.26±.07 .07±.05 .00±.05	.21±.06 .35±.04 .20±.05	.21±.07 .08±.05 .14±.05	
Melodic taste	.14±.07 .14±.05 .14±.05	.06±.08 .06±.05 —.02±.05	.08±.07 .16±.05 .20±.05	.23±.06 .16±.05 .13±.05	.23±.07 .11±.05 .11±.05	.05±.08 .20±.05 .06±.05	.14±.07 .06±.05 .12±.05	.40±.06 .05±.05 —.06±.05	.14±.07 .00±.05 .04±.05

*Drake (5) has reported a correlation between pitch and memory of .02±.10 (school boys).

E. INTERCORRELATIONS[29]

In Table 13 are given the test intercorrelations. The top values in each box are for the Stanford subjects, the center for the eighth-graders, and the bottom values for the fifth-graders. In only two instances are the correlations .40 or above, a result not unexpected.

In a study in which 67 music majors at Colorado State Teachers College were tested (4) the total K-D score was found to correlate as follows with the individual battery members: tonal memory, .52±.06; quality, .54±.06; intensity, .31±.07; tonal movement, .58±.06; time, .40±.07; rhythm discrimination, .44±.07; pitch discrimination, .30±.07; melodic taste, .54±.06; pitch imagery, .53±.06; and rhythm imagery, .46±.07.

F. K-D BATTERY AND "INTELLIGENCE"

It might appear logical to predict that little relationship will be found between this battery and the

TABLE 14

K-D BATTERY VS. THORNDIKE TEST

Test	r P.E.
Tonal memory	.25±.06
Quality	−.04±.06
Intensity	.04±.07
Tonal movement	.15±.07
Time	.00±.07
Rhythm discrimination	.19±.07
Rhythm imagery	.07±.07
Pitch discrimination	.01±.06
Pitch imagery	.00±.07
Melodic taste (20 items)	.22±.07

[29]These values are not corrected for attenuation.

Thorndike test which is employed as a measure of college aptitude. In a check of this idea at Stanford University with sophomore psychology students, the results were as predicted.

A second study of the relationship between the K-D battery and intelligence was recently made. Sixty-seven music majors at the Colorado State Teachers College (4) were given the K-D battery and the American Council Psychological Examination. The total scores on the K-D battery and the intelligence tests correlated $.26 \pm .08$. The individual music tests with one or two exceptions checked well the present writer's results.

TABLE 15

K-D BATTERY VS. AMERICAN COUNCIL PSYCHOLOGICAL EXAMINATION

Test	r P.E.
Tonal memory	$.06 \pm .08$
Quality	$.09 \pm .08$
Intensity	$-.01 \pm .08$
Tonal movement	$.22 \pm .08$
Time	$.20 \pm .08$
Rhythm discrimination	$.03 \pm .08$
Rhythm imagery	$.58 \pm .06$
Pitch discrimination	$-.12 \pm .08$
Pitch imagery	$.33 \pm .07$
Melodic taste	$.38 \pm .07$

In a third study recently reported in a master's thesis, Test (40) found the total K-D battery correlating $+.03$ with the Thurstone intelligence test. One hundred seventy-five music students at Syracuse University served as subjects.

G. SEX DIFFERENCES[80, 81]

Sex differences were figured for fifth- and eighth-graders and college subjects. In Tables 16, 17, and 18 the means which favor the girls have the sign — before them.

TABLE 16
FIFTH GRADE

Test	Males N	Males M	Males Sigma	Females N	Females M	Females Sigma	D/σ_D
Tonal memory	97	14.5	2.4	91	14.2	2.4	.6
Quality	98	21.8	2.8	91	21.3	3.0	1.1
Intensity	98	20.1	4.5	91	—20.3	3.8	.3
Tonal movement	98	14.8	3.7	91	13.7	3.3	2.3
Time	98	14.5	2.8	91	—15.0	2.8	1.3
Rhythm discrimination	97	15.6	2.7	91	—16.0	2.5	1.1
Pitch discrimination	98	22.3	3.7	91	—21.0	3.2	1.4
Melodic taste	98	11.8	2.4	91	—12.5	2.8	1.8
Pitch imagery	98	13.4	2.1	91	13.4	1.9	0.0
Rhythm imagery	98	14.3	2.7	91	—14.5	3.3	.4

[80]At the time this monograph was sent to press no data were available on racial differences. Since then, however, the Sanderson paper (35*b*) has appeared in which claims are made for significant racial differences. The present writer does not wax enthusiastic over such data. The problem of motivation, a difficult one at best, seems most perplexing when racial differences are being studied. Local as well as racial cultures may loom important. Previous studies of the Seashore tests have shown the Negroes to be both better and poorer than whites. This divergence of results may have been due to differences in the personalities of the testers, to more or less white intermixture, to differences in motivation, or to a number of other factors. It should be noted that Sanderson's best group, the Jewish, was composed of orphanage subjects from the seventh to the tenth grades, while her remaining racial groups were all from the eighth grades of the Chicago Public Schools. Lack of similarity between the two sets of environments might easily account for Sanderson's score differences.

[81]The manuscript (now published, see reference 39*a*) of a study by Sward has also been recently examined. In his examination of 93 Jewish and 176 non-Jewish ten- and eleven-year-olds no significant score differences appeared when the tonal movement test was employed.

There are no critical ratios which approach at all closely to 3, the minimum accepted by certain statisticians as necessary for the indication of significant differences.

TABLE 17
EIGHTH GRADE

Test	Males N	M	Sigma	Females N	M	Sigma	D/σ_D
Tonal memory	100	16.3	2.7	109	16.2	2.9	.3
Quality	100	22.4	2.8	109	22.2	2.3	.6
Intensity	100	22.2	2.9	109	—22.4	2.3	.6
Tonal movement	100	15.1	5.5	109	—16.1	5.4	1.2
Time	100	16.5	3.4	109	—16.7	2.7	.3
Rhythm discrimination	100	17.9	2.5	109	17.9	2.3	0.0
Pitch discrimination	100	25.4	4.1	109	25.4	4.1	0.0
Melodic taste	100	12.7	2.4	109	—13.3	2.4	1.8
Pitch imagery	100	14.0	2.4	109	—15.0	2.4	2.9
Rhythm imagery	100	17.4	3.0	109	—17.5	2.8	.1

The critical ratio for the pitch imagery test might be considered as barely significant. As this test is primarily an achievement test, it is the guess of the present writer that this difference may be merely a reflection of a tendency for the eighth-grade girl to have had slightly more musical training than her boy colleague has had. Data covering descriptions on the part of the subjects concerning their musical training tended to verify this. Such questionnaire values, however, may not be reliable or valid.

The girls in this group estimated themselves as more musical than did the boys (D/σ_D of 5.02). This may mean that the former are more interested in music or that the latter wish it to be thought that they are the less musical. The girls claimed slightly more formal musical training (D/σ_D of 1.85), although they were

TABLE 18

COLLEGE LEVEL

Test	N	Males M	Sigma	N	Females M	Sigma	D/σ_D
Tonal memory	126	19.9	3.0	102	18.5	3.1	1.3
Quality	126	24.5	2.3	102	22.6	3.6	4.6
Intensity	214	24.2	1.9	114	22.9	3.4	3.8
Tonal movement	108	22.3	5.6	101	—22.7	5.2	.5
Time	147	20.7	2.2	103	19.1	2.4	6.7
Rhythm discrimination	148	19.4	2.1	103	18.9	2.1	1.9
Pitch discrimination	228	28.6	3.4	129	28.5	3.4	.2
Melodic taste	107	16.0	2.4	102	14.8	2.7	3.5
Pitch imagery	108	16.9	3.1	101	16.3	3.1	1.5
Rhythm imagery	110	19.6	2.5	100	19.1	2.9	1.2

significantly poor on several of these tests.

The present writer does not feel that any data he has seen are pertinent to the issue of native sex differences in musical capacities and abilities. Even if the K-D and Seashore tests are granted to be music tests, the sex differences on these tests are small and differ with the several age groups.

H. ITEM DIFFICULTIES

Under certain conditions it is important to know how various groups of subjects react to the individual items of the tests. In other words, do different groups agree as to the degree of difficulty of the several items? In the data to be reported in Table 19, 200 fifth-graders, equally divided as to sex, were separated in a chance shuffling into two equal groups, termed A and B. The percentages of errors for each test item were tabulated. When the various A's and B's were correlated the results were found to be: tonal memory,

TABLE 19

PERCENTAGE ERRORS IN FIFTH GRADE

	Tonal memory A B	Quality A B	Intensity A B	Tonal movement A B	Time A B	Rhythm discrimination A B	Pitch discrimination A B	Melodic taste A B	Pitch imagery A B	Rhythm imagery A B
1	1-21	10- 7	25- 6	23-31	21- 3	17-18	43-37	23-14	10- 5	7- 3
2	44-28	5- 6	27-11	27-23	41-57	39-34	37-34	34-32	42-39	68-45
3	11-21	6-11	20-10	33-23	47-62	9- 8	54-66	32-24	55-36	63-45
4	39-42	7- 3	17- 6	39-25	20- 7	14-16	36-26	49-59	42-64	75-60
5	15-21	14- 5	17-24	51-46	60-69	18-13	34-21	44-28	49-52	9-18
6	81-86	5- 4	60-52	43-41	51-77	38-31	65-73	45-43	44-60	31-35
7	77-72	75-70	75-82	48-58	17-15	62-51	29-25	48-41	59-54	51-50
8	22-19	47-37	75-67	53-62	73-67	54-50	53-73	47-55	50-62	42-44
9	69-53	81-93	37-40	42-52	21-19	15- 7	68-77	45-40	52-53	58-51
10	47-40	5- 9	19-11	57-54	78-75	8-17	78-82	44-33	50-59	46-46
11	21-20	12- 7	57-81	46-44	85-83	22-30	18-15	38-22	54-36	32-24
12	76-54	55-64	29-14	47-52	21-14	54-43	31-24	44-32	44-41	34-43
13	74-69	9-11	39-23	58-65	18-16	20-16	39-30	32-26	47-32	40-47
14	18-37	15- 6	23-13	55-56	81-84	60-55	47-58	52-55	55-52	47-43
15	61-63	8- 2	18-12	49-51	69-72	23-17	56-18	34-30	52-31	33-38
16	19-26	51-52	24- 7	68-76	13-19	83-84	39-16	40-43	55-58	23-36
17	23-28	8- 7	24- 7	65-76	31-19	25-22	67-68	36-39	52-35	53-54
18	55-49	56-49	19-11	45-31	64-66	23-38	40- 9	47-60	37-26	60-68
19	46-58	11- 6	21-11	64-71	19-15	83-77	27-19	47-32	58-40	66-44
20	29-26	90-79	31-39	62-60	63-63	40-22	60-68	50-39	50-54	35-23
21	24-38	9-16	45-24	51-51	46-40	51-55	53-42		50-35	25-22
22	73-85	44-46	78-85	67-73	22-17	28-33	25-20		48-36	37-36
23	10-30	9- 7	77-73	69-73	13-14	64-55	37-33		57-44	33-24
24	78-52	6- 4	23-28	56-45	46-37	73-64	27-17		54-63	36-49
25	22-20	73-65	18-15	33-42	14- 8	29-24	24-22		60-55	64-69
26		9- 9	64-49	55-46			61-50			
27		8- 4	63-43	59-50			27-23			
28		50-68	50-19	70-71			63-68			
29		62-70	13-18	67-76			71-65			
30		20-10	18- 8	67-78			63-82			
31							44-20			
32							29-37			
33							50-34			
34							64-48			
35							31-23			
36							28-27			
37							70-75			
38							36-25			
39							59-23			
40							56-80			

.87±.03; quality, .97±.01; intensity, .94±.02; tonal movement, .91±.02; time, .98±.01; rhythm, .93±.02; pitch, .79±.04; melodic taste, .78±.06; pitch imagery, .52±.10; and rhythm, .81±.05.

An exactly similar procedure was undertaken for the eighth grade (Table 20). The corresponding correlations were: tonal memory, .95±.02; quality, .95±.01; intensity, .95±.01; tonal movement, .91±.02; time, .77±.06; rhythm, .93±.02; pitch, .90±.02; melodic taste, .92±.02; pitch imagery, .96±.01; and rhythm imagery, .75±.06.

The college data were similarly treated (Table 21). The corresponding correlations were: tonal memory, .96±.01; quality, .93±.02; intensity, .99±.01; tonal movement, .98±.01; time, .95±.01; rhythm, .98±.01; pitch, .86±.03; melodic taste, .91±.03; pitch imagery, .94±.01; and rhythm imagery, .95±.01.

The means of Groups A and B for the three age groups were correlated to learn how consistent the errors were. The coefficients are given in the following order: fifth versus eighth, and eighth versus adult. The values (in terms of rho) are: tonal memory, .94, .75; quality, .90, .94; intensity, .87, .93; tonal movement, .88, .76; time, .95, .66; rhythm discrimination, .89, .93; pitch discrimination, .86, .62; melodic taste, .87, .84; pitch imagery, .72, .84; and rhythm imagery, .74, .68.

In summarizing, it can be said that the item errors of the K-D battery are quite consistently made. In the main, the various age groups make similar errors. For these reasons the tests are of use whenever group

	Tonal memory A B	Quality A B	Intensity A B	Tonal movement A B	Time A B	Rhythm discrimination A B	Pitch discrimination A B	Melodic taste A B	Pitch imagery A B	Rhythm imagery A B
1	5-17	7- 8	4- 1	11-13	5-10	4- 1	51-35	10- 7	7- 1	1- 0
2	26-20	0- 3	2- 1	7- 5	24-45	9- 5	33-39	19-17	56-37	42-17
3	3- 5	2- 2	4- 3	11-11	30-39	1- 1	71-45	29-28	8- 7	31-23
4	30-17	7- 1	4- 4	19-20	7-13	2- 8	15-19	56-60	77-94	59-67
5	2-14	9- 3	20-16	38-21	51-32	9- 6	15-16	24-21	68-66	11-13
6	81-80	3- 3	53-36	20-17	69-65	22- 2	68-54	43-31	72-77	17- 2
7	86-72	73-72	92-90	23-15	8-24	90-91	18-30	36-33	13-13	40-23
8	3-13	34-46	48-54	67-77	72-53	29-26	60-64	54-64	72-66	42-37
9	59-44	95-93	39-64	59-75	13-19	8-10	87-77	51-35	75-59	57-28
10	41-44	1- 9	12-12	49-58	80-65	3-20	86-74	35-36	71-74	35-19
11	10-14	8- 6	57-53	40-54	87-60	18-15	12- 5	15- 7	14-18	16-14
12	57-35	70-70	7- 6	53-50	13-27	30-23	19-13	22-15	48-50	23-22
13	73-66	7-14	16-11	64-55	18-22	11-16	24-17	32-26	7-10	35-41
14	20-35	3- 6	6-10	66-59	72-72	42-29	27-17	55-59	72-54	40-28
15	68-58	3- 3	5- 4	50-53	82-46	22-15	34-22	31-17	12-11	21-21
16	12-23	46-48	6- 4	73-64	17-17	75-86	24-17	46-30	63-71	21-20
17	17-12	4- 6	4- 0	76-66	22-24	21-10	61-57	35-30	21-14	52-28
18	53-50	41-46	4- 3	19-25	50-30	33-27	25-19	61-72	20-13	64-52
19	33-19	8- 1	5- 4	62-59	23-17	88-83	20-14	39-34	17- 8	35-18
20	9-18	76-69	51-34	65-56	39-35	27-19	68-60	34-32	67-53	11-15
21	21-29	20- 7	20-12	52-58	26-33	60-45	29-23		39-27	16-24
22	76-62	25-57	88-85	59-59	14-22	20-22	19-17		28-25	46-51
23	16-19	3- 8	86-83	66-55	14-20	46-48	17-12		42-44	39-34
24	75-72	4- 4	21-29	43-28	22-17	47-48	11-12		82-75	31-33
25	21-22	67-53	13-21	44-55	11-22	20-18	31-17		25-30	58-29
26		3- 2	53-47	54-53			48-22			
27		9- 8	57-36	46-53			16-13			
28		58-65	19-11	65-55			68-54			
29		65-70	12- 9	71-55			60-40			
30		7- 8	4- 3	84-73			74-87			
31							22- 5			
32							22-26			
33							41-15			
34							43-27			
35							37-31			
36							24-28			
37							91-65			
38							23-40			
39							21-30			
40							66-65			

TABLE 21
PERCENTAGE ERRORS, COLLEGE*

	Tonal memory	Quality	Intensity	Tonal movement	Time	Rhythm discrimination	Pitch discrimination	Melodic taste	Pitch imagery	Rhythm imagery
1	1	10	2	6	2	3	11	1	1	2
2	3	5	3	0	2	5	19	14	11	8
3	4	3	4	6	2	0	22	22	2	7
4	10	3	5	21	0	2	15	24	72	61
5	5	9	32	14	13	4	13	15	41	15
6	64	3	20	9	44	6	25	41	61	3
7	48	57	93	11	10	75	16	24	22	11
8	6	37	98	37	53	19	27	42	70	17
9	40	91	75	29	4	3	66	20	25	8
10	11	9	7	24	50	4	52	33	54	5
11	22	13	49	17	57	12	3	2	22	8
12	18	47	3	44	10	13	16	13	46	20
13	42	18	10	26	19	5	6	19	15	27
14	38	13	5	26	61	11	6	26	54	19
15	26	5	6	31	38	27	40	9	26	15
16	22	31	2	41	17	91	31	35	60	21
17	18	3	2	37	23	11	18	23	7	46
18	41	36	4	17	24	40	30	48	10	53
19	13	8	5	37	25	61	50	18	18	20
20	25	50	44	43	12	33	39	31	25	8
21	34	21	9	28	5	42	6		24	14
22	48	39	96	30	19	37	9		34	51
23	26	14	75	33	17	31	7		28	20
24	49	4	40	28	6	43	12		67	57
25	48	24	18	39	20	30	44		46	52
26		12	29	38			19			
27		16	17	34			31			
28		45	5	27			44			
29		61	9	33			28			
30		14	4	53			53			
31							3			
32							21			
33							12			
34							34			
35							26			
36							35			
37							70			
38							40			
39							53			
40							57			

* Separate tabulations for Groups A and B were also made for this table. Although they were lost, retabulations were not considered necessary. The values in this table give the averages of A and B.

responses to the various items are to be studied.[32]

I. Age Differences

A glance at the means given in Section G suffices to demonstrate the fact that the eighth-graders made higher scores, on the average, than did the fifth-graders. The critical ratios are all significant, although age differences in the quality and tonal movement tests barely exceed the required value of 3 (i.e., required by certain statisticians). Similarly, the differences to be found between the eighth-graders and the college subjects are all significant.[33] Pronounced age differences are also reported in studies by Barnard (1*a*) and by Whitley (46).

In a previous monograph (7) the present writer has discussed Seashore's conception of cognitive and physiological limits. In that discussion it was stated that there is no way of knowing for certain whether the age differences are due (1) to a progressively increasing ability on the part of the subject better to understand such tests, or (2) to some sort of maturation or training process in the capacities in question. A similar conclusion must be made for the K-D battery. This theoretical consideration, however, does not alter the fact that more than one set of norms should be offered.

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[32]It is interesting to note the close correspondence between degree of item difficulty and type of response. In the tests in which "S" and "D" are the responses, the "S" 's are more generally the easy items and the "D" 's, the difficult.

[33]For age differences in reliability and item difficulty, see other sections.

J. Norms

The norms offered by Kwalwasser and Dykema (20) were based upon scores earned by 2000 grade- and high-school students. Age, grade, sex, and other variables were ignored in the construction of percentiles. That this is not justified was seen in the section on age differences. In examining the present writer's data it was noted that already at the fifth-grade level the mean of the quality scores surpassed the fiftieth percentile of the original K-D norms. By the time the eighth grade is reached the mean scores of the tests of tonal memory, intensity, rhythm discrimination, melodic taste, and rhythm imagery have surpassed the fiftieth percentiles of the K-D norms. Since all this demonstrates quite decisively a need for other norms, new ones were constructed and are given in Tables 22, 23, and 24.[34] They were based on the scores of approximately 188 fifth-graders, 209 eighth-graders, and from 207 to 486 adults.

That the norms are not appreciably different when the panatrope is employed is shown in Table 25. The test of melodic taste was the only one in which the first rendition on the panatrope gave a significantly higher mean (critical ratio over 3) than when the non-electric phonograph was used. (See Table 18. The averages of the two sexes were compared with the data of Table 25.)

[34]Tilson has also found the K-D norms worthless for college students. However, Tilson's mean and median percentiles should be high for two other reasons: first, he was testing students enrolled in a music course; and, secondly, tests were given two or three times; the highest scores only were preserved (41, 42).

Tonal memory		Quality discrimination		Intensity discrimination		Tonal movement		Time discrimination	
Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
25	100	29+	100	28+	100	30	100	25	100
24	95	28	96	27	96	29	90	24	97
23	87	27	88	26	86	28	79	23	91
22	77	26	73	25	61	27	68	22	79
21	67	25	60	24	36	26	60	21	64
20	59	24	45	23	21	25	54	20	48
19	47	23	31	22	12	24	49	19	35
18	32	22	19	21	8	23	45	18	22
17	22	21	11	20	6	22	39	17	16
16	13	20	7	19	5	21	34	16	11
15	8	19	5	18	3	20	31	15	7
14	5	18	4	17	3	19	24	14	5
13	3	17	3	16	2	18	21	13	3
12	2	16	2	15	2	17	18	12	2
11	1	15	1	14	1	16	16	11	1
						15	11		
						14	9		
						13	6		
						12	5		
						11	4		
						10	2		
						9	1		

Rhythm discrimination		Pitch discrimination		Melodic taste		Pitch imagery		Rhythm imagery	
Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
24+	100	35+	100	20	100	25	100	25	100
23	98	34	97	19	90	24	98	24	99
22	92	33	91	18	76	23	97	23	95
21	74	32	83	17	60	22	93	22	82
20	51	31	70	16	40	21	90	21	65
19	32	30	58	15	27	20	86	20	45
18	21	29	45	14	19	19	80	19	28
17	14	28	32	13	11	18	70	18	17
16	8	27	26	12	5	17	54	17	12
15	4	26	20	11	4	16	41	16	9
14	2	25	14	10	3	15	28	15	6
13	1	24	11	9	2	14	18	14	4
		[illegible]	[illegible]	[illegible]	[illegible]	13	10	13	3

TABLE 23

PERCENTILE RANKS—EIGHTH GRADE

Tonal memory		Quality discrimination		Intensity discrimination		Tonal movement		Time discrimination	
Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
25	100	29+	100	28+	100	29+	100	24+	100
24	99	28	99	27	99	28	99	23	99
23	99	27	99	26	98	27	97	22	97
22	99	26	96	25	96	26	95	21	93
21	97	25	90	24	87	25	92	20	89
20	93	24	80	23	65	24	90	19	82
19	89	23	67	22	47	23	88	18	72
18	79	22	55	21	27	22	83	17	62
17	70	21	37	20	19	21	81	16	49
16	56	20	23	19	12	20	79	15	36
15	41	19	11	18	9	19	77	14	27
14	28	18	7	17	7	18	75	13	17
13	17	17	3	16	4	17	68	12	11
12	11	16	3	15	3	16	62	11	5
11	4	15	2	14	2	15	54	10	3
10	1	14	2	13	2	14	48	9	2
		13	1	12	1	13	42	8	1
						12	34		
						11	27		
						10	18		
						9	13		
						8	6		
						7	2		
						6	1		

TABLE 23 (*continued*)
PERCENTILE RANKS—EIGHTH GRADE

Rhythm discrimination		Pitch discrimination		Melodic taste		Pitch imagery		Rhythm imagery	
Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
23+	100	35+	100	20	100	24+	100	23+	100
22	99	34	99	19	99	23	99	22	97
21	96	33	99	18	98	22	99	21	94
20	87	32	97	17	96	21	99	20	85
19	72	31	96	16	93	20	98	19	73
18	57	30	89	15	85	19	97	18	62
17	43	29	84	14	73	18	96	17	49
16	28	28	74	13	56	17	90	16	37
15	18	27	64	12	42	16	79	15	25
14	9	26	58	11	27	15	65	14	17
13	5	25	50	10	16	14	54	13	12
12	3	24	40	9	8	13	38	12	6
11	1	23	31	8	4	12	19	11	3
		22	25	7	1	11	10	10	1
		21	20			10	4		
		20	12			9	1		
		19	8						
		18	6						
		17	4						
		16	3						
		15	1						

TABLE 24
PERCENTILE RANKS—FIFTH GRADE

Tonal memory Score	Rank	Quality discrimination Score	Rank	Intensity discrimination Score	Rank	*Tonal* movement Score	Rank	*Time* discrimination Score	Rank
20+	100	28+	100	28+	100	26+	100	23+	100
19	99	27	99	27	99	25	99	22	99
18	96	26	97	26	98	24	99	21	98
17	90	25	89	25	96	23	99	20	97
16	81	24	84	24	88	22	98	19	94
15	66	23	75	23	79	21	97	18	89
14	51	22	63	22	67	20	95	17	84
13	34	21	49	21	54	19	92	16	73
12	24	20	33	20	47	18	87	15	64
11	11	19	22	19	40	17	83	14	55
10	5	18	16	18	34	16	79	13	38
9	3	17	7	17	25	15	66	12	27
8	2	16	5	16	20	14	58	11	9
7	2	15	3	15	14	13	49	10	4
6	1	14	2	14	9	12	33	9	2
		13	1	13	6	11	22	8	1
				12	6	10	14		
				11	4	9	9		
				10	3	8	4		
				9	2	7	2		
				8	2	6	1		
				7	1				

TABLE 24 (*continued*)
PERCENTILE RANKS—FIFTH GRADE

Rhythm discrimination		Pitch discrimination		Melodic taste		Pitch imagery		Rhythm imagery	
Score	Rank	Score	Rank	Score	Rank	Score	Rank	Score	Rank
22+	100	32+	100	18+	100	18+	100	23+	100
21	99	31	99	17	98	17	99	22	99
20	97	30	98	16	96	16	92	21	99
19	92	29	97	15	89	15	86	20	97
18	84	28	94	14	83	14	75	19	94
17	70	27	90	13	66	13	60	18	90
16	59	26	84	12	55	12	30	17	84
15	43	25	78	11	41	11	16	16	73
14	32	24	72	10	29	10	8	15	62
13	20	23	62	9	16	9	4	14	53
12	12	22	50	8	9	8	2	13	40
11	6	21	36	7	5	7	1	12	27
10	3	20	29	6	2			11	15
9	1	19	21	5	1			10	10
		18	13					9	6
		17	6					8	2
		16	3					7	1
		15	1						

TABLE 25

PANATROPE DATA

Test	Mean	Sigma
Tonal memory	18.7	2.7
Quality	23.7	2.5
Intensity	23.7	2.3
Time	18.5	2.9
Melodic taste	16.3	2.1
Tonal movement	21.7	4.6
Pitch discrimination	28.6	2.6
Rhythm discrimination	19.1	1.9
Pitch imagery	16.6	3.2
Rhythm imagery	18.7	2.6

Analyses of the retest means given below indicate that in the second rendition (after approximately one and one-half months) there were slight but generally signicant increases in the majority of the means. These increases may be due to errors of selection. The writer does *not* believe this to be true as the subjects of the retest were chosen at random from the larger original groups. Table 26 is to be compared with Table 18. The data thus indicate that norms based on retest material will be different from those just presented. A similar condition was found to be true with the fifth- and eighth-grade results, although the increases on the second renditions were not so marked or so regular with the grade-school subjects.[85]

K. TRAINING

In a study by Chadwick (4) 67 music majors at Colorado State Teachers College were tested on the K-D battery. They were also given the American

[85] These data are on file, but have been excluded to save space.

TABLE 26
RETESTS OF ADULTS

Test	Mean	Sigma	N
Tonal memory	19.8	3.1	78
Quality	25.1	2.3	78
Intensity	24.4	1.5	77
Tonal movement	24.5	4.2	74
Time	20.8	2.8	73
Rhythm discrimination	*19.4*	*2.0*	*73*
Pitch discrimination	29.3	3.0	72
Melodic taste	16.0	2.1	104
Pitch imagery	17.2	2.8	104
Rhythm imagery	19.2	2.0	104

Council Psychological Examination. The duration of the subject's musical training was tabulated in terms of years. The major effort was to predict grades in sight-singing. In the table below are given the correlations which were found to exist between the music tests and years of training.

TABLE 27
K-D BATTERY VS. TRAINING

Test	Training
Tonal memory	.26±.08
Quality	.19±.08
Intensity	.14±.08
Tonal movement	.26±.08
Time	.24±.08
Rhythm discrimination	.07±.08
Pitch discrimination	.20±.08
Melodic taste	.12±.08
Pitch imagery	.33±.07
Rhythm imagery	.25±.08
Total score	.42±.07

Few of the values are near .40. The two imagery tests are, obviously, measures of achievement (to a great extent), and, therefore, might be expected to give higher correlations than the average. As has

been pointed out previously by a number of workers, a high correlation between the amount of training people have had and their scores on a capacity test does not yield definite information. Training may have improved the capacity in question. On the other hand, the highly endowed may receive more training than the less gifted.

In a study by Barnard (1), grade-school children who had had no music lessons, either class or individual, scored lower on the K-D battery than did those who had had training.

L. Validity

Chadwick (4), by employing path coefficients, developed the following regression equations: X_{16} equals $.03X_2 - .01X_3 + .01X_4 - 3.45$ . . . where X_{16} is the sight-singing grade to be predicted, X_2 is the total score on the K-D battery; X_3, the training in years; and X_4, the score on a certain intelligence test. Where an A grade in sight-singing is 5.00; a B, 4.00; a C, 3.00; a D, 2.00; and an F, 1.00; the sigma estimate is .635. This means that the predicted grade has 2 chances in 3 of being within about two-thirds of a letter grade of the mark which the student will attain. In discussing the prediction of sight-singing grades, Chadwick has said: "When the joint influences are apportioned according to the ratio of the direct influences, aptitude accounts for about eighteen per cent, intelligence for about six per cent, and training depresses the influences about two per cent, leaving a residue of influence approximating 77 per cent."

In this work the reliabilities of the tests were not ascertained. Although the "residue of influence" is enormous, an interesting and perhaps worth-while start has been made toward the establishment of a critical level. Newly entering students who score below this value can perhaps be safely dissuaded from work in music[80] unless their interest is very great and there is plenty of time and money at their disposal. As a rule the practical interests of the music school must also be considered.

TABLE 28
K-D BATTERY VS. GRADES IN SIGHT-SINGING

Test	Sight-singing
Tonal memory	.37±.07
Quality	.19±.08
Intensity	.28±.07
Tonal movement	.31±.07
Time	.02±.08
Rhythm discrimination	.08±.08
Pitch discrimination	.01±.08
Melodic taste	.23±.08
Pitch imagery	.52±.06
Rhythm imagery	.34±.07
Total score	.41±.07

Tilson (41,42) has also studied the possible relationships between the K-D scores and quarter grades in

TABLE 29
K-D BATTERY VS. GRADES IN EAR-TRAINING AND SIGHT-SINGING

Test	r P.E.
Tonal memory	.40±.06
Quality	.21±.07
Intensity	—.17±.07
Tonal movement	.25±.07
Time	—.03±.07
Rhythm discrimination	.19±.07
Pitch discrimination	—.12±.07
Melodic taste	.19±.07
Pitch imagery	.19±.07
Rhythm imagery	.39±.06

[80]Not found as yet.

ear-training and sight-singing. His values are presented in Table 29.

Neil (29), in a master's thesis, demonstrates that there is little or no relationship (r's between .40 and —.36 which average slightly positive) existing between the K-D intensity, time, and rhythm tests and a weight discrimination test of his own construction. A considerable number of high-school and college students served as subjects.

In another master's thesis can be found the report of Test (40) on 175 music students of Syracuse University. She found that the K-D battery correlated .37 with grades from courses in which skill in musical performance was stressed; in the same connection, the Thurstone (psychological) test correlated .17. The K-D and intelligence tests combined correlated .48 with "All Fine Art" grades.

Drake (5) obtained teachers' ratings of students enrolled in several academies of music in England. Pitch imagery correlated .81±.05 with the ratings; intensity, .44±.13; and tonal memory, .34±.10 (reduced to .20±.10 when age and training were partialed out).

One might expect that a group of students who are enrolled in a college course in music would score considerably higher on the K-D tests than did the Stanford subjects in the psychology classes. A measure the writer has of this point comes from a test made on San Mateo (California) Junior College students who were taking a course in college music. As can be seen by comparing Table 30 with Table 18 there were a few

significant differences. The Stanford group might perhaps be considered as just significantly better in the tests of pitch discrimination, melodic taste, and tonal memory. The San Mateo subjects did slightly better (signicant critical ratio) in rhythm imagery. The results are somewhat surprising. They may indicate: (1) that the tests, in a strict sense, are not music tests; (2) that there was poorer motivation at San Mateo; (3) that the Stanford subjects are more musical than the writer had previously supposed. As far as the writer can see, there is no possibility of giving a definite answer at present.

TABLE 30

SAN MATEO DATA

Test	N	Mean	Sigma
Tonal memory	77	18.0	2.5
Quality	67	23.4	2.4
Intensity	67	23.5	2.7
Tonal movement	66	21.9	4.6
Time	72	20.1	2.3
Rhythm discrimination	72	19.2	1.8
Melodic taste	50	13.8	2.8
Pitch discrimination	50	27.0	2.8
Pitch imagery	69	16.0	2.3
Rhythm imagery	69	20.3	2.0

M. CRITICAL RÉSUMÉ

This study clearly indicates that the Kwalwasser-Dykema battery is quite inferior psychologically to the older Seashore tests. The former tests do offer a few advantages. They are shorter and less tiresome. The stimuli are more musical and so, perhaps, more pleasing to musical groups. As the items are announced by number, the testing procedure is made more fool-

proof. The tests are recorded on small records and can be carried in neat cases. Certain of these improvements, however, have been made at the expense of reliability.

Several of the present writer's ablest subjects (with best auditory limens) have claimed that the pitch test is very inaccurate. Tilson makes a similar statement in his report (41, 42). However, no definite study has so far been reported on the physical exactness with which the stimuli are given.

Insufficient data are at hand relative to the matter of validity. It is apparent that the K-D and Seashore tests are not measuring to any large extent the same behavior variables. And as to reliability, one can clearly see they (K-D) are decidedly inferior to those constructed by Seashore. These newer tests should probably be employed solely in studies of group differences.

APPENDIX

A DEVICE FOR PUNCHING BLANK PLAYER-PIANO ROLLS[37]

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Within the last few years player pianos have been recognized as presenting an opportunity for research in the psychology of music. The use of these instruments in investigation has been severely restricted, however, by the great labor and inaccuracy of punching blank rolls by hand. The instrument herein described considerably reduces the labor and increases the accuracy of this task. The accompanying plate indicates in diagram the essentials of the apparatus.

The player roll to be punched is put in place at *J*. The paper is led from there between the roller *C* and the rubber roller *E*. The latter is held against *C* by means of a spring which is not shown in the drawing. From these rollers the paper is passed under plate *H* and above the platform *F*. The tab at the forward end of the roll of paper is attached to the peg *L* in the roller *K*. The paper is kept under tension by the weight *N* attached to a string which is wound around the spool *M* fastened on the axle of the roller *K*. The paper is prevented from rolling forward by means of the rachet *B*. The operator causes the paper to move by turning the knob *G*, much as one moves the paper in the carriage of a typewriter. The rachet is so made that the position of the paper can be changed as little as approximately one-sixteenth inch if desired.

The heavy line labeled *D* indicates a row of holes which are spaced exactly as are the holes in the tracker board of a player piano. These holes are round and have a diameter equal to that of the width of the holes in the tracker board. They extend through the plate *H* and through another steel plate in the platform *F* directly under plate *H*. The paper passes between these plates and the holes are punched in it by means of a hand punch pushed down from above.

[37] This machine was designed by the writer of this appendix and built by Mr. F. D. Banham, the Stanford University mechanician, for the author of the monograph.

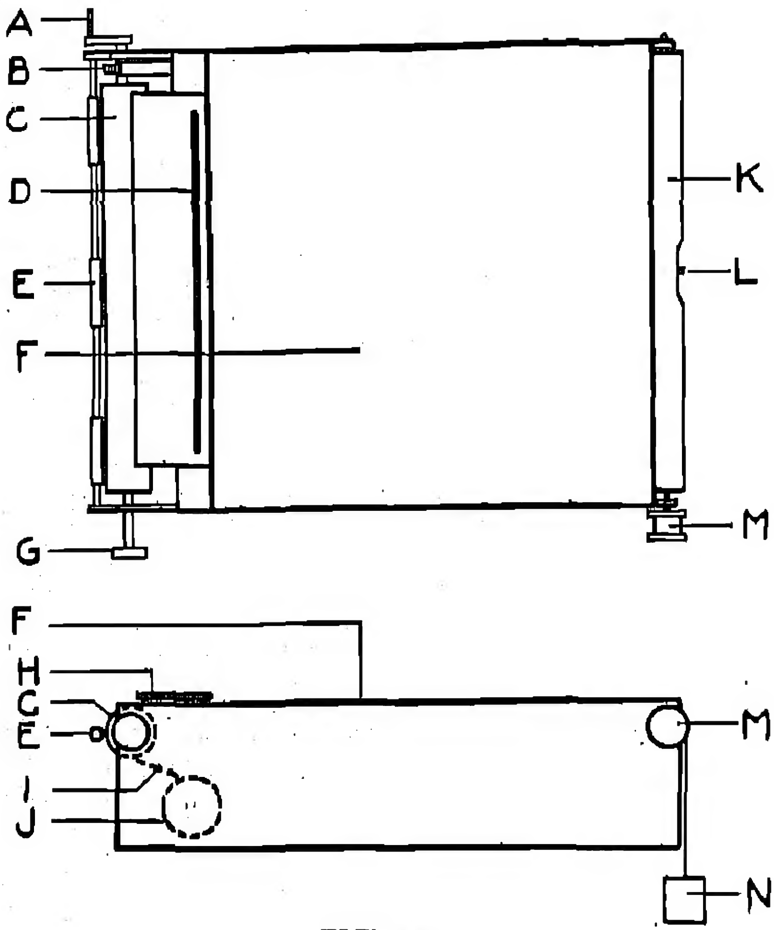

FIGURE 1

DIAGRAMS OF A DEVICE FOR PUNCHING BLANK PLAYER-PIANO ROLLS

Upper: Plan view of the apparatus
Lower: Side view of the apparatus

Description in text.

This punch (which is not shown in the drawings) is made from round steel of the same diameter as the holes in the plates and is provided with a wooden handle. It is square across the cutting-end and makes a clean-cut perforation. A strip of paper is glued on plate *H* adjacent to the row of holes showing the notes represented by the respective holes.

By use of the appropriate holes at the ends of the row the operator can punch the paper so as to regulate the intensity at which the music is to be played. *A* is a crank for rewinding the roll after it has been punched.

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ÉTUDES DANS LA PSYCHOLOGIE DU TON ET DE LA MUSIQUE

(Résumé)

Ce monographe comprend une série d'articles relativement sans rapport les uns aux autres sur la psychologie du ton et de la musique.

Dans le chapitre I on montre qu'une plus grande connaissance de la musique est associée à une plus grande tendance à classifier les éléments du ton comme "bons" plutôt que comme "mauvais".

Dans le chapitre suivant on discute les rapports entre le talent musical et la gaucherie. Les résultats des questionnaires ne soutiennent pas les prétentions antérieures que la gaucherie et le talent musical ont des rapports positifs. Cependant, les individus ambidextres ont un avantage en se dirigeant vers leurs buts techniques dans la musique.

Selon les observations rapportées dans le chapitre suivant il y a un facteur social embarrassant qui opère quand on compare le jazz et la musique 'acceptée'. Ce dernier type de musique est probablement évalué le plus justement.

Dans le quatrième chapitre on reproche les psychologues à cause de leur traitement du bruit et de la dissonance. *Ces phénomènes ne sont pas per se* désagréables. Ils offrent non seulement des contrastes avec la musique consonante mais, même sans l'aide de celle-ci, ils causent fréquemment le plaisir.

Dans le chapitre 5 on discute des questionnaires et des données expérimentales sur les rythmes croisés. On présente une nouvelle méthode Gestalt d'acquérir les rythmes croisés.

Dans le chapitre 6 il s'agit de l'emploi des méthodes modernes pour exprimer les préférences en termes d'unités sigma. On donne des ordres de rang de préférence pour des "diades" chromatiques et des intervalles d'un quart de ton présentés simultanément et successivement. On appuie surtout sur le résultat que les préférences pour certains quarts de ton qui n'apparaissent pas dans la gamme chromatique sont plus grandes que pour d'autres qui sont 'musicalement' employés.

Le chapitre 7 présente descriptions des moyens dont un psychologue peut se servir d'un piano mécanique. On rapporte dans un appendice un appareil pour faire des trous dans les rouleaux pour piano mécanique.

Dans le chapitre 8 on montre que la nouvelle formulation de la loi Lipps Meyer par les auteurs n'est bonne que pour le tempérament égal.

On présente ensuite d'autres études des batteries de tests de musique de Seashore et les plus vieilles batteries de Kwalwasser. Les modifications Gaw des tests de Seashore de 'Sens de temps' et de 'Mémoire tonale' se montrent meilleures que ceux-ci. Puisque les percentiles de l'auteur pour le test de Seashore de 'Sens de rythme' et les 35573 tests de Kwalwasser Victor diffèrent beaucoup de ceux donnés par les auteurs de ces tests, on les présente ici.

Le dernier chapitre contient une étude détaillée des tests de musique de Kwalwasser-Dykema. On présente des données sur les cohérences, les intercorrélations, les rapports aux tests 'd'intelligence' et les tests de Seashore, les différences de sexe et d'âge, les difficultés des points, etc.

FARNSWORTH

UNTERSUCHUNGEN IN DER PSYCHOLOGIE DES TONS UND DER MUSIK

(Referat)

Diese Monographie umfasst eine Serie relativ unverwandter Artikel über die Psychologie des Tons und der Musik.

Im ersten Kapitel *wird bewiesen, dass zunehmende Bekanntheit im Bereich der Musik mit einer zunehmenden Neigung einhergeht, Tonelemente eher als "gut" wie als "schlecht" zu klassifizieren.*

Im *nächsten Kapitel* wird die Beziehung zwischen *musikalischem Talent* und Linkshändigkeit besprochen. Frühere Behauptungen im Sinne einer *positiven Beziehung zwischen Linkshändigkeit* und musikalischem Talent werden durch Befunde, die mit Fragebogen erzielt wurden, nicht unterstützt. Gleiche Geschicklichkeit beider Hände [ambidexterity], aber, stellt für die, die sie besitzen, in ihrem Streben nach technischen Zielen in der Musik einen Vorteil dar.

Nach Beobachtungen, die in dem nächsten Kapitel notiert werden, gibt es stets bei dem *Vergleich* zwischen dem "*Jazz*" und der "anerkannten" Musik eine verwirrende Einwirkung. Die letztere Art wird wahrscheinlich gerechter beurteilt, als die erstere.

Im vierten Kapitel werden die Psychologen wegen ihrer Behandlung der Lärm- und Dissonanzfragen getadelt. Lärm und Dissonanz sind *an sich nicht unangenehm. Sie bereiten nicht nur der konsonanten Musik einen* Kontrast, sondern erzeugen oft auch ohne deren Hilfe Gefallen.

Im *fünften* Kapitel bespricht der Verfasser mit Fragebogen und Versuchen erhaltene Befunde über kontrastierende Rhythmen [cross rhythms]. Es wird *eine neue Gestaltmethode zur Bemeisterung der kontrastierenden* Rhythmen dargeboten.

Kapitel 6 bezieht sich auf die Verwendung der modernen Methoden zur Notierung von Bevorzugungen [expressing preferences] mittels Sigmaeinheiten [sigma units]. Es werden Bevorzugungsrangordnungen [rank orders of preference] in Bezug auf simultan und aufeinanderfolgend dargebotene Reizungen mit chromatischen Diaden [dyads] und Vierteltonintervallen notiert. Es wird besonders der Befund betont, dass die Bevorzugung gewisser Vierteltöne, die in der chromatischen Tonleiter nicht vorkommen, stärker ist, als die Bevorzugung anderer Töne, die musikalisch verwendet werden.

Kapitel 7 enthält Beschreibungen der verschiedenen Weisen, auf die ein *mechanisches Klavier* [player piano] *von einem Psycholog verwendet werden* kann. In einem Anhang wird ein Verfahren zur Durchlöcherung von Trommelwirbeln für das mechanische Klavier [punching player piano rolls] notiert.

Im achten Kapitel wird demonstriert, dass des Verfassers Neuformulierung *des Lipps-Meyer'schen Gesetzes nur für das wohltemperierte* Instrument gültig ist [holds only for equal temperament].

Dann werden weitere Untersuchungen der Testserien von Seashore und (in der älteren Form) von Kwalwasser zur Prüfung der musikalischen Fähigkeit beschrieben und besprochen. *Die von Gaw eingeführten* veränderten Formen der Seashore'schen Prüfungen des "Rhythmusgefühls" [sense of time] und des "*Tongedächtnis*" [tonal memory] haben sich als den ursprünglichen Prüfungen überlegen erwiesen. Da die Prozentsätze *[percentiles] die von dem gegenwärtigen Verfasser* mit der Seashore'schen

Prüfung des Rhythmusgefühls und mit den Kwalwasser Victor 35573 Tests erhalten wurden, von den durch die ursprünglichen Verfasser erhaltenen stark abweichen, werden sie hier angeführt.

Das letzte Kapitel enthält eine ausführliche experimentell-statistische Besprechung der Musiktests von Kwalwasser-Dykema. Es werden Befunde angeführt in Bezug auf Zuverlässigkeiten, Interkorrelationen, Beziehungen zu Intelligenz und zu den Seashore Tests. Geschlechts- und Altersunterschiede, Schwierigkeit der einzelnen Bestandteile der Prüfungen, u. s. w.

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GENETIC PSYCHOLOGY MONOGRAPHS

Child Behavior, Animal Behavior, and Comparative Psychology

MOTOR LEARNING OF CHILDREN IN EQUILIBRIUM IN RELATION TO NUTRITION*[1]

From the Department of Psychology of The Johns Hopkins University

By

ELINOR LEE BEEBE

*Accepted for publication by Buford Johnson of the Editorial Board and received in the Editorial Office, May 11, 1933.

[1]This report is part of a dissertation presented in conformity with the requirements for the Degree of Doctor of Philosophy at The Johns Hopkins University. The work was made possible by a National Scholarship in Child Development, 1928-30, from the Committee on Child Development of the National Research Council.

Worcester, Massachusetts

Entered as second-class matter December 1, 1925, at the post-office at Worcester, Massachusetts, under the Act of March 3, 1879

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Grateful acknowledgment is made to Dr. Knight Dunlap for guidance and assistance in this study; to Dr. Buford Johnson for instruction and direction in the techniques of psychological research with young children; to Dr. Roy M. Dorcus for criticism and practical suggestion; to Dr. E. V. McCollum for counsel and assistance with regard to evaluation of nutritional relationships; and to Dr. Lowell J. Reed for advice as to treatment of records and data.

ELINOR LEE BEEBE

BUREAU OF EDUCATION
ALBANY, NEW YORK

CONTENTS

I

HISTORICAL PRESENTATION

A. Nutritional Relationships

The relation of behavior to nutrition constitutes a problem which has long interested investigators. Its various phases have been the subject of many types of experimentation, and a considerable body of knowledge has been accumulated, particularly associated around what from the viewpoint of the psychologist may be called the grosser manifestations.

Growth is known to be altered by the state of nutrition. Growth of different body tissues is known to be *differently affected*, in the period of fastest growth the skeleton being particularly favored at the expense of the muscles especially, but of other parts also. This has been noted by Waters (145) on calves, by Aron (4) on dogs, by Jackson and Stewart (75) on rats, and by Hess (49, 50) on malnourished infants.

Perhaps to the psychologist the more important point here is the permanent impairment either in size or in differential structure caused by interference in growth. Osborne and Mendel (123, 124) conclude that satisfactory adult weight may be attained by realimentation after even excessive periods of growth suppression produced either by quantitative reduction of diet or by a large variety of qualitatively faulty diets. However, the data of Aron and the exhaustive studies of Jackson and Stewart directly oppose the re-

sults of Osborne and Mendel. Jackson and Stewart, after study of over three hundred rats from 46 litters for approximately a three-year period, report: "In no case in which the underfeeding from birth was prolonged beyond three weeks did the test rats upon ample refeeding reach the maximum weight of the normal controls in the same litter." From underfeeding in a second group, begun after the first three weeks and extended over longer periods, the authors state: "In not a single case did the maximum weight upon refeeding reach that of normal controls in the same litter."

Boas (18), in analyzing growth studies of children, comes to a conclusion also opposing that of Osborne and Mendel: ". . . excessive retardation is an unfavorable element in the growth and development of the individual."

Physiological age and functional development of the organs concerned in reproduction have been shown to be markedly affected by the nutritional state. Aron's dogs, though of the age of maturity, still had the bark of young puppies and the muscular tissue exhibited qualities of the young rather than of the mature animal. Eckles (28, 29) for calves, and Crampton (24, 25), Baldwin (5-8), and others working with children show a positive relation between size and the chronological age at which sexual maturity takes place.

Muscular strength has been believed to be positively associated with nutrition on the basis of results such as those of Smedley (140), using records of the ergograph. The work of Smedley, and also more recently of Hollingworth and Taylor (65), supports the same

conclusion as to strength of grip measured by the dynamometer. Such factors as motivation are recognized as having variable influence here.

For a time the relation of mental ability to nutrition held considerable interest for psychologists. The height-weight-age index and various tests of muscular strength were most frequently used as a measure of nutrition, and grade in school, teachers' estimates, and, later, intelligence tests as a measure of mental ability. Johnson's (76) study of mental growth of children in relation to rate of growth in bodily development is cited as one of the more extensive investigations in this field. Her conclusion that "mental age of a group of the same chronological age does not show a significant relationship to weight and height" is illustrative of results generally obtained. The emphasis placed by Baldwin (9) and others upon the influence of physiological maturity as conditioning intellectual achievement was apparently an outgrowth from such investigations.

Gates (42, 43) essayed a rounding-up of this whole question. He gives a summary of the pertinent studies, a chronological table of the representative work dealing with relation of physical and mental traits, and a selected bibliography to 1924. He concludes that the physical measurements are valuable, but that mere physical status or maturity, however adequately measured, apparently does by no means gauge mental, educational, social, or emotional maturity satisfactorily.

Hollingworth and associates (64, 65, 120), with pairing and a wide differentiation in intelligence of the

groups studied, found children who test over 135 IQ (Stanford-Binet) superior in scholastic achievement, in size, strength, and speed. Interest along this line has diminished, perhaps due to the widely conflicting results, the unsatisfactory measures, and the recognition of the presence of a large number of variable factors difficult of control. Roberts (130) has supplied a careful critical analysis of the field and with it a selected bibliography. Paterson (126) has brought out an extended treatment of the various questions involved in relationship of physique and intellect, covering all available quantitative studies during the past 40 years. He concludes that "prevalent notions regarding an intimate relation between bodily traits and mental development have been greatly exaggerated." However, Paterson (47) makes the statement: "The possibility that a closer connection between physical development and mental development may be discovered during the preschool period of childhood must constantly be borne in mind." He urges application of all lines of such investigation to research with infants and young children. With the evidence of this field thus so carefully reviewed in successive epochal summaries, no further detailed presentation is attempted here.

Behavior admittedly has many aspects so closely interacting as to be extremely difficult to separate and to control. Nutrition also has been proved to take in many delicately balanced chemical ratios and many associated governing influences not easily amenable to conditions necessary for a reliable study. A large num-

ber of subtly contributing variable factors are therefore obviously concerned in the total solution of the problem of this relationship between behavior and nutrition, and it has been necessary for the investigation of the several parts of the pattern to wait upon the successive accretions of knowledge and the development of applicable techniques not only in the field of psychology but also in biochemistry and physiology. Biochemistry, through its consistent employment of adequate control in the biological method, has made outstanding contribution to the progress of science. Knowledge of nutrition has been advanced with great rapidity and along lines of fine differentiation, such as are called for in the problem now under discussion. Physiology too has made contributions which have bearing upon the chemistry of glandular and muscular functioning and other phases of this question. Psychology, although as stated above formerly evincing great interest in correlation of intelligence with various physical manifestations, has been slow to make use of these facts more recently brought forward with regard to nutrition and its implications for the reaction of the organism. There are legitimate reasons for this delay. The control of the nutritional condition of human reactors offers great practical difficulty. In animal experimentation the repetition of significant work in nutrition with testing of its psychological implications offers more hopeful possibilities, but for accurate results probably necessitates considerable extension and modification of laboratory facilities. In addition, the desirability of histological, chemical, neurological,

and anatomical confirmation of data on the experimental animals places a considerable burden of organization upon such experimentation. Finally, the selection and refinement of psychological tests adapted to bring out any existent relationship is in itself a major task. Though many gaps still exist with regard both to desirable information and needed methods of approach, yet seemingly sufficient data of a highly significant character are now at hand to justify specific experimentation pointed toward investigation of the relation between nutrition and behavior in its various phases.

With the recent introduction by Dr. Knight Dunlap (26, 27) of a somewhat revolutionary hypothesis concerning brain function and his emphasis upon the determining power of the periphery with regard to individual differences in capacity, we have moreover from the psychological field a fruitful working hypothesis which leads sooner or later into the problem of the chemical variations of peripheral tissues and of body fluids. The main principles supporting the Dunlap (27) hypothesis are summarized in the succeeding paragraphs.

"The brain is an integrating organ, and we know of no other function which it has." On the other hand, "discriminatory perception depends primarily upon the building of a difference in muscular response. . . . Perception is a matter of habit formation."

With all statements carefully guarded against possibilities inherent in pathological conditions, and with due credit to the mutual interplay between forces of hereditary tendency and of environmental influence

with regard to variations in mental characteristics and capabilities, the claim is made that, as regards the brain, the actual differences in normal individuals are due to differences in training alone. "The training of the individual is therefore primarily the training of his brain," and "the brain is the trainable organ *par excellence.*"

"The training processes originate in the environment, acting through the mechanisms of receptors, glands of inner secretion and muscles." The emphasis here placed upon skeletal muscle is highly significant as in the statements:

> "The brain is an essentially plastic organ, especially in infancy and early youth, capable of meeting any demands which the receptors, the muscles and the glands, are able to make upon it systematically. . . . . The variations occur in the capacity of the peripheral mechanism to administer the training. . . . . The muscles are not merely immediate agents in adaptation to environment; they furnish a continuous component in the stimulus pattern, and hence a constant factor in training . . . . As for the differences in the chemistry of different individuals, and in the function of such peripheral mechanisms as the muscle plate in its relation to the muscles, where slight variations would be capable of producing large results, we have not even scratched the surface of the problems. The investigation of these peripheral factors I believe to constitute the most pressing problems of psychology."

Much data from different fields must be accumulated to constitute conclusive proof or disproof of the principles outlined. The Dunlap hypothesis, however, at this time serves a highly important purpose in directing effort away from abstruse constructions and into objec-

tively fruitful investigations. It is worth while to examine the literature with a view to bringing together data bearing upon the influence of chemical variations upon the reactivity of peripheral tissues, particularly muscular tissue.

Several psychological researches have been brought forth which show recognition of the necessity for exploration and mapping-out of the range of presumed relationships between nutrition and behavior. These use animal experimentation and hinge on learning ability.

Anderson and Smith (2) in 1926 made a notable beginning with a study of the effect of stunting upon maze learning in the white rat. They expressed the opinion at that time that "not only should much of the fundamental classical research be repeated in the light of this newer knowledge (of nutrition) but that many problems not primarily nutritional in character can be attacked, using the improved feeding methods now available." These authors reasoned that "if metabolism, reproduction and growth are so profoundly affected by inadequate nutrition, might it not be expected that the physiological processes concerned with learning, memory and habit formation would also be altered by such conditions?" To test this idea, they paired three groups of female rats on the basis of maze records, giving optimum, "qualitatively stunting," and "quantitatively stunting" diets.

On the criterion of time, the results from relearning show that, although the three groups made very similar performances on the first learning (prior to stunting),

after 28 days' stunting both "qualitatively" and "quantitatively" stunted groups were much faster than normal control rats in running the maze. Following a second period in which all groups were given the same diet, more nearly the same records are shown again. The investigators conclude from these results that stunted rats are superior in relearning a maze to rats that grow normally.

The investigation gives a method of attack highly significant for psychologists. Its authors advance the possibility that stunting produces increased drive and makes the animals more active and alert in the maze and that realimentation may lessen and equalize the drive. They state that quantitatively stunted animals run very much more rapidly per unit of time than do either the qualitatively stunted or the normal rats. It is therefore possible that this experiment does not clearly differentiate learning capacity. Perhaps one conclusive statement can be made on the basis of this evidence, namely, that gliadin stunting at the stage of life at which here introduced produces no harmful effect upon learning ability.

Upon this beginning the same authors (3) have built a further significant investigation hinging upon the *motivation and the age factor. With regard to errors* made in running a maze, the statement is made: "Since more errors are made in less time, this finding would indicate that stunted rats run more rapidly than do normal rats and would fall in line with the findings as to increased activity and support a motivation hypothesis."

Realimentation eliminates the majority of differences in performance except in maze running, where superiority of the normal group in time and errors may perhaps be ascribed to the error habit of stunted rats as shown in earlier trials. The interesting observation is made that, in general, in performance stunted animals appear to be "nearer normal animals of their own weight, than animals of their own age but of normal weight."

Frank (36) uses a rachitic group, an equalized quantitatively stunted group, and an optimum-diet group for study of maze-learning ability. Immediate and delayed effects of rickets are tested beginning at an age of 30 to 35 days. She reports: "Rats with active rickets learned the maze in fewer trials than normal rats, and with fewer errors, but they consumed more time in learning," an increase out of proportion to rachitic motor involvement. The shorter time and increased errors of quantitatively stunted animals agree with the findings of Anderson and Smith. A similar agreement is present in the disappearance of differences in maze learning after realimentation of the stunted groups and in the superiority of normal rats in relearning a maze.

Frank concludes that: "If differences in learning ability do exist in normal, rachitic and underweight animals, the usual maze technique is inadequate for their demonstration."

With regard to stunting, McCollum and Simmonds (107) make the statement:

> "It is true that rats which are stunted by means of protein starvation retain for long periods their capacity to resume growth. The form of the grown animal is closely similar to that of rats whose growth to adult size has been uninterrupted. McCollum and Simmonds (unpublished data) have found, however, that rats kept upon diets, the inorganic content of which was unsatisfactory, develop abnormal frames and become deformed. Any nutritive regimen which will induce rickets will markedly interfere with subsequent growth.
>
> "Animals whose growth has been suspended by depriving them of either vitamin A or B are able to resume growth upon the inclusion of the missing substance in the diet. It is impossible, however, to carry animals on such diets for long periods."

McCollum and Simmonds (107) have also made significant statements as to qualitative changes in the protein of the diet.

> "A large group of rats were restricted to diets which were faulty in different degrees with respect to the quality of their protein. The experiments included the period of growth, and of adult life, at least to the point of development of senile characters. Fertility and success in the nursing of young, the stability or instability of the nervous system as shown by indifference to being handled, which is characteristic of well-nourished rats, or the apprehensiveness and timidity of many malnourished ones, were carefully observed. Successive generations of the families, where young were reared, were maintained on the family diet. The deviation of the quality of the protein moiety of the diet even in slight degrees from the optimum, exerted a profound influence on the life history of the animals and on the functioning of the nervous system."

They further state that the faults of a diet need not be greatly pronounced to produce physical deteriora-

tion when such a regimen is adhered to over any considerable period.

Just recently, Maurer and Tsai (100) in a well-controlled investigation secured results of arresting implication from a study of the effects of early vitamin B depletion upon *maze-learning* ability of adult white rats. Depletion in the antineuritic vitamin is peculiarly important for research bearing upon learning ability, though perhaps not wholly for the reason stated by the authors that "it has been universally accepted that learning ability is primarily a function of the nervous system." Suckling rats were drastically depleted of vitamin B through the mother's diet until weaned. After weaning, the depleted group was brought up to approximately the weight of the control group reared on an optimum diet throughout, and, for 28 days previous to the maze learning, experimental and control groups were given the same complete diet. Food was always in the cages, thus eliminating extreme hunger. Nevertheless, the authors report both groups as eager for the incentive wheat germ. This careful control of motivation by Maurer and Tsai is of outstanding importance for all investigation of behavior changes in groups differentiated on a basis of nutrition. Otherwise, the nature of the nutritional change may in itself cause an accompanying change in motivation and thus introduce a potent source of error, as pointed out previously. The results obtained from the depleted and the normal groups justify the investigators' statement that "with all criteria of measurement (trial, error, retracing, time) normal rats exhibit far better

average and median scores in maze learning than those which have been depleted in vitamin B through the mothers' diet during the nursing period. Normal rats are about twice as efficient as depleted animals." Pairing of records of animals in litters having the same parents and pairing of records by weight show the same results as mentioned above.

The authors state that a neurological and a chemical research on these groups are also in progress, which results will be correlated with the findings already published. They are deserving of much commendation, not only for careful control of a number of variable factors, but for this effort to include a report on the neurological and chemical changes to the end that as much information as possible shall be gleaned from the experiment.

A study by Fritz (40) of maze performance of the young adult rat includes a vitamin B deficiency in one group, but obscures its effects by inclusion also of complex mineral changes (iron, iodine, chlorine).

Some further examination of the facts associated with vitamin B deficiency as brought out by former experimenters is necessary for fuller interpretation of this recent work, even though results of earlier work may be somewhat clouded by lack of knowledge of the vitamin B complex and of the associated vitamin G. However, on this point McCollum (107) states that "it has been demonstrated that a deficiency of this substance (vitamin B) causes a degeneration of certain peripheral nerves with paralysis and atrophy of the corresponding muscles." In beri-beri, a deficiency

disease associated with lack of vitamin B, nerves of motion and of sensation are both markedly affected. McCarrison's (103) work shows the loss of the co-ordinating power of the muscles as the most striking manifestation of the polyneuritis produced by this deficiency. Polyneuritic birds, however, show rapid recovery from nervous symptoms when complete diet is supplied. The severe vitamin B depletion of suckling rats in which the nervous system is incompletely developed may be expected to have produced marked inhibition of the development or even degeneration of peripheral nerve tissues. Such extensive injury during the developmental stage must presumably preclude complete regeneration, thus permanently impairing the connections of both afferent and efferent routes. The Maurer-Tsai experiment may therefore have partially accomplished for the periphery, as regards both somatic receptors and effectors, what the Franz (37) isolation of the occipital cortex accomplished for the retina. Some further qualitative description of the depleted group might here be of significance with reference to regeneration. What is the comparative speed of movement of the two groups, irrespective of maze learning? Are anomalies of any kind present in the gait or other movements of the depleted rats?

The results of this experiment as thus far published appear to fit into the Dunlap hypothesis. Early vitamin B depletion presumably produces extensive peripheral injury to the connections from receptors to effectors. The peripheral mechanism, in consequence, being partially shut off, becomes incapable of adminis-

tering a brain-training comparable to that experienced by the undepleted rats. Verification or disproof of the premise must await report of the histological changes discovered in the depleted rats. The importance of the inclusion of histological evidence in such psychological studies involving nutrition is obvious.

Because of the pronounced immaturity of the rats at the time of depletion, it is entirely possible that changes in brain and spinal cord and in other tissues may be found sufficient to confuse the issue. For this reason, so highly significant an investigation may well be supported by at least two repetitions, one planned for half-grown rats, and one for young adult rats. In each of such repetitions, an initial learning series, paired grouping with drastic depletion previous to a second learning series, realimentation, and a final learning series should add significant information. The more nearly complete histological picture to be secured from the succession of experiments using depletion in (1) the suckling period, (2) later growing period—after weaning, and (3) young adult life seems particularly valuable to psychology at this time. Examination of histological changes in nerve-cell structure should be supported also by investigation as to changes in the muscle cell. This evidence with the related learning records for each stage of life is highly important with reference to the Dunlap hypothesis, and hence to a better understanding of learning.

The Dunlap hypothesis placed particular emphasis upon the function of the effectors, that is, glands and skeletal muscles, for purposes of training. The con-

ditions of reactivity of glandular tissue are omitted here, although a considerable body of supporting evidence is available on that phase of the problem. The muscle plate also, upon which there is recent significant data, is disregarded in order to center discussion more clearly upon the two factors of nerve connection and skeletal muscle. This narrowing of the peripheral field is legitimate, since obviously, if training is dependent upon response, it is dependent likewise upon the reactivity of those tissues concerned in that response. Admittedly, skeletal muscles play a major part in response.

In line with this narrowing of the field under discussion, it may perhaps tentatively be assumed that the vitamin B depletion experiment holds constant (at least comparatively speaking) the factor of the condition of skeletal muscle while varying the factor of nerve connection. It is desirable also to examine this relation from the opposite approach. What are the inferences as to results to be obtained from holding constant the nerve connection and varying the nutritional state of the muscular tissue? The reactivity of any tissue is clearly dependent upon the stimulability of its component cells. Thus is envisaged the fundamental importance of changes in cellular structure and in the chemistry of blood and lymph, together with the ultimate relationship of response to nutritional factors acting upon cell and fluid. The Dunlap hypothesis, with its emphasis upon the training function of skeletal muscle, leads directly to the consideration of the supporting evidence relating to the chemistry of muscle-cell reactivity.

In order to ferret out the possible lines of connection between nutritional influences and cellular reactivity of muscles, it is necessary to examine two groups of evidence: (1) What is the influence of nutritional elements upon the essential structure of the muscle cell and hence upon its reactivity? (2) What influence upon muscular reactivity has the chemical variation of those body fluids, the blood and lymph, which nourish these cells?

The researches having bearing upon the power of nutrition changes to produce consequent changes upon the essential structure of the cell are first to be considered. By structural change is meant a modification of the cell in its nuclear or cytoplasmic content such as to affect characteristics other than size. Long-continued change in characteristic shape of the cell is considered as produced by structural modification. It is assumed that an axiomatic statement may be made that change *in structure produces some consequent change in the* reactivity of the cell.

Data are now available to demonstrate that specific changes in diet produce structural changes in the cells of epithelial, endothelial, and bone tissues. Deficiency of vitamin A has been shown by Wason (144), Yudkin and Lambert (148, 149), Mori (121, 122), Evans and Bishop (31), Wolbach and Howe (146, 147), and others to be associated with stratified horny changes of the normal epithelium. According to work of Wolbach and Howe (147), in men and in the rat a specific effect of vitamin A deficiency is seen in epithelial structures and results in the substitution of stratified

keratinizing epithelium for normal epithelium in the respiratory tract, alimentary tract, eyes, parocular glands, and genito-urinary tract. Mason (99) has shown that male rats fed an inadequate amount of vitamin A become sterile within a few weeks even when an abundance of vitamin E is present. The germinal epithelium of the testes degenerates and sperm-cell formation ceases. So uniformly associated with epithelial changes is depletion in vitamin A that Macy, Outhouse, Long, and Graham (91) have designated the presence of keratinized epithelial cells in the vaginal smears of virgin rats as an early and reliable sign of vitamin A deficiency suitable for use in the biological assay of foods for vitamin A. McCollum and Simmonds (107) rate this procedure for making the assay as probably the most accurate available method.

McCollum (106) has summarized the effects of deficiency of vitamin C as follows:

> "Deficiency of vitamin C has been shown to affect primarily the endothelial cells forming the capillary blood vessels. . . . . the influence is manifested in a loss of power to produce the cement substance holding the endothelial cells together in the membrane. Recently Höjer (63) has pointed out that before the circulatory system is damaged to an observable degree, the odontoblastic layer lying next to the dentine in the pulp cavity of the teeth suffers alteration in structure."

Sufficient evidence appears to be available for the conclusion that endothelial cells may be altered in structure by nutritional changes.

The production of marked changes in the structure of developing bone cells by alteration of nutrition with

regard to the calcium-phosphorus ratio and the vitamin D control is abundantly demonstrated in a long list of careful experiments. Associated with these nutritional changes, a recognized zone of abnormal growth occurs at the end of the shaft. This zone, known as the rachitic metaphysis, shows a wide variety of histological changes, blood vessels, connective tissue, osteoid, marrow elements, and cartilage cells in all stages of degeneration and metamorphosis into other tissue. There is a tendency to persistence of cartilage with lack of calcification.

Extended series of experiments by McCollum and co-workers (104, 108-113), Shipley and co-workers (139), Sherman (134), Mellanby (115), Hess and associates (52, 53, 56), Steenbock (141), Bills (15-17), and others attest to these structural changes. Carefully prepared sections of bone tissue showing the histological changes associated with the producing dietary changes are available. So characteristic and uniform are these histological changes that the McCollum (107) "line test," consisting in the dietary production of the rachitic metaphysis and observation of the 5-day amount of calcification produced along the horizontal line attendant upon healing, is widely used in connection with biological assay of foods as to vitamin D potency.

Very recently, Klein, Becker, and McCollum (77) have secured the striking evidence in tooth structure of alternate bands of deficiently calicified and of more thoroughly calcified structure coinciding in general to alternate periods of feeding on a strontium and on an adequate diet.

The preceding findings are reviewed here in an attempt to find an answer to the question: What is the influence of nutritional elements upon the essential structure of the muscle cell and hence upon its reactivity? A great weight of evidence is available on this point with regard to epithelial, endothelial, and bone tissue. Presumably, similar proof is present for nerve tissue, though this has not been systematically presented here on account of some clouding of the results from the vitamin B complex and vitamin G, the so-called antineuritic and antipellagric factors. Kruse and McCollum (81) have just reviewed the literature on the antineuritic vitamin.

Mention of the accompaniment of muscular changes is also found in the literature, but the histology of these changes seems not to have been so uniformly and systematically investigated as that of the tissues previously mentioned. Jackson (74), in a summary of the effects of total inanition upon the musculature, states that "the histological changes in skeletal muscle fibers involve first a simple atrophy—a decrease in size with no evident changes in structure." This accords with the common inference that such muscular changes as occur, since quantitative only, involve nothing other than a weakening of the response. True, it is conceivable that a weakened response may have less training effect than a vigorous response. However, it is noteworthy that Jackson includes other changes as substantiated by the evidence at hand. To quote further:

> "Later, certain of the muscle fibers begin to show degenerative changes with progressive loss of the characteristic

> striations of the myofibrillae, granular (fatty, albuminous or pigmentary) degeneration in the sarcoplasm. . . . The nuclei are more resistant and often undergo proliferation. A variable degree of hyperplasia (fibrosis) occurs in the interstitial connective tissue. The extent of the degeneration varies greatly, not only in different fibers of the same muscle, but also in muscles in different regions of the body."

Similar changes have been reported from depletion of selected nutritional factors. Banu (11), in an investigation of the muscular pathology of human rickets, reports the muscle fibers uniformly atrophied, with disappearance of the cross striations, increased distinctness of the longitudinal striations, multiplication of the muscle nuclei, and increased connective tissue. McCarrison (103) describes changes in the musculature of the polyneuritic chicken and pigeon, and Funk (41) has also noted them in polyneuritic birds. Hess (51, 54, 55), in his work on human and animal scurvy, notes in degeneration of the muscle fibers, hemorrhages, variable pigment deposits, and interstitial fibrosis. Höjer (63), in scurvy, finds hemorrhages, atrophy of the muscle fibers, and necrosis with calcification.

A conservative attitude toward the results now at hand, incomplete though they are at various points, does not prevent its estimation as presumptive evidence that a close relationship exists between nutritional factors and the intracellular structure of muscular and of other tissues. With regard to this whole subject of histological changes, McCarrison (103) considers these nutrient principles now known as vitamins as "certain nuclear ingredients essential for the

nutriment of the living nucleus. They are 'nuclear nourishers' without which multiplication of cells does not occur. The term nucleopast (that which feeds the nucleus) might well be applied to them."

It remains to examine the evidence on the question: What influence upon muscular reactivity has the chemical variation of those body fluids, the blood and lymph, which nourish these cells? To quote Howell (68) on this point, as stated in the eleventh edition (1930) of his *Textbook of Physiology:*

> "The main salts . . . . are bound up in the structure of the living molecule and are necessary to its normal reactions or irritability. Even the proteins of the body liquids contain definite amounts of ash, and if this ash is removed, their properties are seriously altered. . . . . The peculiar part played by the calcium, potassium and sodium salts in the rhythmical contractions of heart muscle, the irritability of muscular and nervous tissues, and the permeability of the capillary walls and other membranes has been referred to."

Howell summarizes the present knowledge with regard to the action of calcium, potassium, and sodium ions in the blood and lymph upon the properties of heart muscle. " . . . there is a balanced activity, and . . . the presence of all three in the proportions found in the liquid of the blood is essential for the normal activity of the heart."

Although in experimental work concerning heart muscle the differences in the muscle structure and in the periodicity of its function need to be kept in mind, yet work confined to skeletal muscle seems to confirm the belief that the same basic principles are operative with regard to the proportionate chemical concentra-

tion of the ions in the blood. A considerable list of brilliant and careful researches has carried forward the body of knowledge as to the action of the chemical ratios of the blood upon muscular tissue. Biedermann (13, 14), Ringer (129), Locke (85), Friedenthal (39), Jacques Loeb (86-89), and others have made valuable contributions. The results of Loeb's investigations, together with the basic principles involved, are here summarized. Muscle preparations (gastrocnemius) of the frog were used in a series of experiments. A muscle placed in pure sodium chloride solution isotonic with the blood soon begins and continues during life to twitch rhythmically. Upon addition of a small definite amount of soluble calcium salt, the twitchings cease, though the muscle lives longer in such a solution than in the pure sodium chloride solution. (Cf. Ringer's solution.) That the capacity for irritability is not lost can be proved by removal of the muscle from the solution and testing by the faradic current. Loeb concluded therefore that we owe it to the calcium and the magnesium ions in the blood that our skeletal muscles do not twitch or beat rhythmically.

A further series of experiments is based on the fact that the muscle itself contains calcium salts capable of precipitation. By putting the muscle into solutions of sodium salts, which by entering the muscle precipitate the calcium contained in it, still more powerful rhythmical contractions were produced. Friedenthal at about this same time showed that the injection into the body of an animal of any salts capable of precipitating calcium is followed almost immediately by

twitchings of all the muscles. Loeb (89) clearly states his belief

> "that the normal qualities, especially the normal irritability, of animal tissues depend upon the presence in these tissues of Na-, K-, Ca-, and Mg-ions in the right proportion; that these ions are at least partly in combination with colloids (proteins or higher fatty acids or possibly carbohydrates), and that any sudden change in the relative proportions of these ion lipoids or ion proteins or ion carbohydrates alters the properties of the tissues and gives rise to an activity or an inhibition of the activity, according to the sense in which the change takes place."

Meltzer and Auer (116) later demonstrated the antagonistic action of calcium upon the inhibitory effect of magnesium. They used the live rabbit and the monkey (Macacus rhesus) and conducted a number of experiments with uniform results. Their facts, as illustrated by intravenous infusion of various calcium salts, support the general conclusion that calcium efficiently antagonizes the abnormal activity of its three inorganic associates in the human body, magnesium, potassium, and sodium, be the activity an over-inhibition or an over-excitation.

Recently, Bouchaert and Belehradek (20) have obtained confirmatory results as to the general principle, though their specific concentration is at variance with that previously used.

On the basis of the blood findings and the clinical symptoms, Kramer, Tisdall, and Howland (80) express the belief that the increased irritability of the neuromuscular mechanism in infantile tetany is due to a reduced concentration of calcium in the blood

serum. In such cases the calcium content of the blood is invariably reduced during active symptoms of tetany. Administration of calcium chloride by mouth, moreover, overcomes the spasm and results in a raised blood calcium.

In the light of the foregoing evidence there can be little doubt that changes in the chemical ratios of the blood must of necessity affect the reactivity of skeletal muscles.

A further transition remains. Do dietary variations of chemical nature, unless of a most drastic type, affect to any significant degree the blood ratios? Or, on the other hand, are there in the human body (and in other animal organisms) sufficient stabilizing mechanisms, as, for example, the parathyroid glands and the buffer reaction of the blood, to render it unlikely that any significant number of the dietary variations which ordinarily occur may constitute nutritional change sufficient to produce a consequent detrimental alteration in chemical blood ratios?

Jackson (74) makes the general statement that, although relatively stable, the blood is found to undergo variable changes in nearly every type of inanition. The term inanition is used by him to designate insufficiency of all nutriment or insufficiency of one or more essential food elements. He further states that "the blood plasma is subject to various changes in chemical composition although for a long time its losses may be restored through absorption from the various tissues."

The data with regard to this point concern chiefly the blood changes associated with rickets and tetany

on which successive careful analyses have been made. Howland and Marriott (71, 72) early noted the normal calcium of human blood as 10 to 11 mg. per 100 c.c. of serum. They find a lowering to 8 mg. in some cases of rickets and an invariable reduction of the serum calcium in active tetany even to as low a figure as 3.5 mg. per 100 c.c. The giving of calcium chloride by mouth causes prompt relief of the spasm and is accompanied by rise of the blood calcium. The serum calcium was found by Kramer, Tisdall, and Howland (80), in a large series of rickets cases associated with tetany, to be about 5.4 mg. or approximately half the normal.

Howland and Kramer (69) found in rickets a marked decrease in the inorganic phosphorus of the serum. In a later report they (70) state for rats a normal serum calcium of from 9.5 mg. to 10.5 mg. and a normal serum phosphorus of from 7.0 to 8.5 per 100 c.c. These normal values are not further increased by diet or by ultra-violet light. However, by feeding diets very low either in calcium or in phosphorus the concentration of these elements in the serum can be diminished by as much as 50 per cent. These effects are, of course, capable of stabilization by cod-liver oil, by the prepared vitamin D, viosterol, or by irradiation.

The work of Howland and Kramer demonstrates the importance of the product of the concentration of calcium and phosphate ions in the blood. They found in uncomplicated rickets a serum having a practically normal calcium but a low phosphorus concentration,

the product of the two figures being at or below 30. In tetany, however, the phosphorus may be near the normal, but a low product results from the striking reduction in the calcium.

Holt, LaMer, and Chown (66, 67), and more recently Adams and McCollum (1), have shown the technical application of this principle of the ion-product values of calcium and phosphorus to indicate whether test animals show active rickets or healing. McCollum and Simmonds (107) state that "the results of blood analyses can be correlated with 'line test' (i.e., histological) observations in practically all cases."

That the blood changes are referable to dietary changes and that these changes proceed on a gradation basis rather than according to an all-or-none principle is shown aptly in Table 1, taken from data of Kramer and Howland (79).

The blood changes here shown were produced in rats subjected for 40 days to the designated diet beginning at an age of 30 days.

It will be noted from the table that, with deficiency of the stabilizing vitamin D, variation in the calcium of the diet produced a closely related variation in the serum calcium. A generally consistent relationship was shown also between the proportion of calcium to phosphorus in the diet and in the serum.

Petersen (127), in a study of ununited fractures, by application of the principles elaborated by McCollum, Simmonds, Shipley, and Park, and by Howland and Kramer, used diets which lowered the serum-phos-

TABLE I

EFFECT OF BUTTER FAT 1%, PHOSPHORUS 0.6%, VARIABLE CALCIUM OF DIET ON CA AND P OF SERUM

From Kramer and Howland (79)

Diet	Ca/P in diet	Serum Ca	Serum P	Weight gain gm.
P =0.6 Ca=0.14	0.24	4.6	11.3	14
P =0.6 Ca=0.24	0.40	5.8	10.1	18
P =0.6 Ca=0.44	0.74	5.6	12.2	20
P =0.6 Ca=0.64	1.07	7.3	11.6	33
P =0.6 Ca=0.84	1.40	8.8	8.9	33
P =0.6 Ca=1.04	1.75	10.0	7.4	40
P =0.6 Ca=1.24	2.07	10.9	6.5	28

phorus concentration in dogs. He produced a condition in which the calcium phosphorus was less than 30. For union of fractures he found it necessary to raise this product again to the normal, which he accomplished by dietary changes.

The responsiveness of the blood chemistry of the human adult to dietary changes is shown in a clinical study of an ununited fracture case also reported by Petersen (128). The initial blood chemistry showed a low calcium-phosphorus product. By giving a

varied diet with daily inclusion of 2.0 gm. of calcium carbonate, 1.0 ounce of cod-liver oil, 500 c.c. of buttermilk, and orange juice or raw vegetables, and also with calves' liver three times a week, the following changes were produced (Table 2).

TABLE 2
EFFECT OF DIET UPON CALCIUM-PHOSPHORUS PRODUCT IN HUMAN BLOOD SERUM
From Petersen (128)

Date	Ca	P	Product
Nov. 7	10.8	2.225	24.0
Jan. 2	10.3	3.75	38.1
Feb. 18	10.4	4.0	41.6

From the foregoing evidence, it appears then that dietary changes in the absence of sufficient regulatory factors produce roughly proportionate changes in the chemical ratios of the blood plasma. Furthermore, such nutritional changes affect intracellular structure of the various tissues. It appears that these changes of the blood ratios and of intracellular structure affect the reactivity of the tissues, muscular tissues as well as others. Dr. E. V. McCollum (personal communication), *from extended observation of rats in various* stages of depletion and in depletion of different nutritive factors and from experience also in building up an exceptionally high standard of optimum nutrition in a rat colony inbred for many years, makes several significant statements which bear upon this general problem.

"1. Rats show early and increasing behavior changes in the course of depletion in certain specific food factors.

"2. These changes in many cases, particularly as in the case of calcium depletion, appear to indicate a hypersensitivity to stimulation, in other words a lowering of the threshold of stimulation. A wide range of behavior variation is however observable.

"3. The changes are such as might be explained on the basis of alterations produced upon cellular activity. Changes in training are not involved since this is routine.

"4. Correction of the dietary deficiency in certain though not in all instances is accompanied by fading out of the behavior anomaly whether of hyperexcitability or of other type."

It may be said that the evidence reviewed seems to show a strong probability that nutritional changes affect tissue reactivity and hence, according to the Dunlap hypothesis, influence greatly the brain-training capacity of the periphery, particularly the muscles.

B. *Analysis of Studies of Equilibrium*

The devising of valid means for testing *in vivo* neuromuscular performance with reference to nutritional condition constitutes a major problem. As a beginning toward this end, a test of equilibrium is here presented, which appears to necessitate a peculiarly delicate type of motor coordination as well as a finely integrated adjustment. A lengthy learning series is used.

This section of the historical development is confined more or less strictly to experimentation having to do with the particular type of test used in this study. Results from work with adults as well as with children are presented as significant for purposes of analysis.

McGinnis (114) gives a review of the studies on motor coordination in general of children, together with a complete bibliography to 1929. Her chronological tables, giving experimenter, tests used, and results obtained, are particularly interesting.

The study of equilibrium dates from relatively early investigations. It has been pursued from the point of view of a variety of interests. However, valuable contributions from the many lines of research still fail to produce a sum total of knowledge sufficient to explain satisfactorily and completely the several factors concerned in the development and maintenance of human equilibrium.

Problems of bodily mechanics appear to have interested the earlier investigators. Their studies of erect bodily posture and of the ability to maintain balance were largely directed toward the location of the center of gravity.

Palmer (125) has made a recent study of the center of gravity in the human body. This report, as yet unpublished, reviews the literature and gives a complete bibliography on the subject.

In line with the findings of the earlier work, the efficiency of the military posture, particularly the "attention position," was called into question. This was early studied in Germany. Luciani (90) reports Vierordt's observations dealing with the topic of equilibration in some detail.

Practical tests of equilibrium have been utilized in medical practice. Lack of steadiness of the organism, whether in locomotion or in ability to hold the upright

posture, is readily observable and for certain judgments demands no delicate techniques. Romberg (131), as early as 1851, in his classical study of *tabes dorsalis* had outlined some of the chief characteristics of static equilibrium, particularly with reference to the pathological. This clinical research brings in an implied emphasis upon the factors of control from the central nervous system. Equilibrium becomes more than a problem of the physics of bodily balance.

Perhaps because of the stimulus of the early work of Romberg, perhaps because of the greater ease in objective measurement, static equilibrium has received the more attention in laboratory investigations. To Vierordt, Luciani gives credit for first using the graphic record in the measurement of sway. The mechanism of the ataxiagraph using a kymograph is a development from this work.

Weir Mitchell as early as 1886 used an objective and numerically accurate method of testing station. With Lewis, he (119) reports lateral sway as about 50 per cent less than anterior-posterior.

Romberg (131), particularly through his emphasis upon the invariable character of the clinical sign which today bears his name, directed attention to the visual factor in static equilibrium. Practically all earlier experimentation employs a differentiation on this basis.

Hinsdale (61) in 1887 made a quite extensive study of the visual factor. He reports that 12 normal adults show an average increase of 54 per cent in sway on both horizontal axes when eyes are closed. With 25 girls of ages 7 to 13 years, closure caused an increase

of 40 per cent. Hinsdale then tested 39 blind subjects, who showed an increase of 76 per cent over normal subjects with eyes open. In 17 deaf mutes closure of the eyes increased the sway only 37 per cent. A later experiment by Hinsdale (62), 1890, shows an increase of sway of 65 per cent in 12 normal adults with eyes closed. The accuracy of the recording devices and also the comparable character of the subjects of the different groups may perhaps be called in question by the range of the deviations reported by Hinsdale.

Hinsdale finds observation of marked sway to right rather than to left in the majority of normal subjects. While right-handed people almost invariably tilt to the right, 12 out of 22 left-handed were inclined to tilt to the left. He states that children sway absolutely more than adults.

Bullard and Brackett (21) in 1888 measured by *means of the ataxiagraph the static equilibrium of* healthy men undergoing competitive physical examination. Their tests show men from 20 to 30 years to be 4 per cent better with eyes closed, a finding contradictory to the usual report. Of the 150 men tested, 80 per cent showed a final head position definitely in front of the starting-position. Miles (118) states that ataxiameter records also show anterior movements nearly always largest. This he attributes to the fact that the point of bearing at the ankle joint is 5 centimeters behind the coronal plane, thus constituting the point of greatest tension and throwing upon the soleus muscles the burden of preventing the falling-forward

of the body. He further states that the soleus muscles appear to relax gradually during the test, allowing the total center of gravity to shift forward.

Hancock (46) in 1894 secured measurements on 158 children from 5 to 7 years of age. One hundred and ten were less steady with eyes closed. Age differences were noticeable in the 3-year range. Sex differences favored the girls.

Bolton (19) used the ataxiagraph in 1903 to study the relation of motor power to intelligence.

Wallin (143) in 1912 gave the ataxiagraph a place in his studies of defective children. He reports sway slightly greater for female than for male epileptics, particularly in the lateral direction. Closing of the eyes increases oscillation in both directions, more for low-grade than for high-grade cases.

Melville (117), 1913, was interested in studying the attention position as required in military practice, the arrangement of the soldier's equipment pack, and the recording of fatigue effects. He gave particular attention to important anatomical considerations apparently in connection with the ataxiagraph findings of other investigators. To quote his statements freely, the human body is practically symmetrically disposed on either side of the sagittal plane, but asymmetrical as regards the coronal plane, which facts largely account for the greater lateral than anterior-posterior stability. It is composed from above downwards of several segments (head, trunk, thigh, leg, foot), each affixed without rigidity to the next. Each segment possesses a center of gravity peculiar to itself which

must be *considered in relation* to the point of support on the segment just below and to the area of support on the ground.

Miles considers sway to be perceived and controlled in so far as this takes place almost entirely through *the lower limbs*. The ankle carries the brunt of the movement of body sway. Here he makes a significant point from the work of Goldscheider (44), who has reported the ankle as the least sensitive of the large joints to angular rotation, the threshold being from *.75° to 1.50°* It is in the soleus muscles in their relation through the ankle joint that the subject most actively exerts control to maintain a fine balance. The ataxiagraph, in short, in Miles's opinion records the play of forces between these muscles and all that may act as antagonistic to them.

The earlier use of the ataxiagraph in military research in connection with problems of bodily mechanics was greatly augmented by the development of aviation. Many tests related to body equilibrium attained prominence because of apparent value for predicting ability in flying. The ataxiagraph was used with aviation candidates mainly as a test of the condition of physiological and psychological control. Stratton (142), and also Henmon (48), gave it a place among tests of value in predicting flying ability.

Miles (118), in 1922, in the Nutrition Laboratory of the Carnegie Institution of Washington, developed a device for automatic summation of movement in the two opposed axes of the horizontal plane. This facility of measurement added to the practical value of the

ataxiagraph and stimulated still further use of this latest mechanism, now known as the ataxiameter. He gives a thorough discussion of its significance for various purposes, together with a critical analysis of the data brought out during the earlier development as well as by subsequent experimentation extending up to the year 1922.

Miles considers that the data examined recommend the station test as a sensitive measure of neuromuscular control in selecting men for work and in assessing their condition after work or when subjected to various modifying influences. He presents additional original data in support of the statement that sensations arising from changes of pressure on different parts of the soles of the feet and of strain within the feet are of great use in controlling equilibrium. Habituation to shoes makes it advisable to wear shoes for the test, though the practiced bare foot at a comfortable temperature is probably more sensitive, in addition to furnishing advantageously a larger base of support. The greatest stability is found when heels are about 20 centimeters apart. Height and weight are both shown to cause increased sway, height having the greater effect.

Miles's data support the earlier work of Hinsdale as to an influence by respiration. The indication is for easy normal breathing during the test. The influence of distraction is stressed with the suggestion that attention be controlled by instructing subjects to count silently with a clock's tick.

Fearing (32-35), in 1924 and 1925, using the ataxia-

meter, made an extensive study of a large number of the factors influencing sway. His data are significant on many points and, among other things, suggest that control and direction of attention are the chief factors on the conscious side in the decrease of sway with practice. Following this lead, he made a study of practice, securing results which indicate that the appearance of practice effects is accompanied by significant changes in the direction of attention.

Fearing next studied the effect of controlled and uncontrolled attention upon sway, using for control the distraction of a Wundt sound hammer at discontinuous periods, counted and reported by the subjects. The results show significant decrease of sway in the distraction group which perhaps throws emphasis upon the involuntary factor in the processes concerned in maintenance of static equilibrium.

Problems of perception of tilt, investigations of the function of the semicircular canals, and specific studies of bodily rotation admittedly have relationship to studies of equilibrium. Griffith (45) has reviewed the literature on vestibular equilibration and has published a complete bibliography to 1922. Fearing (35) has brought the evidence with supporting references up to 1930.

It is desirable to present a brief summary of those facts having to do with the control of posture by the central nervous system. Langworthy (83) gives a clearly stated critical review on this topic which covers the literature up to 1928. Cobb (22) and Hines (58-60) have made recent analyses of subjects closely

related. A complete bibliography is included in each instance.

The original work of Sherrington (136) in the demonstration of the postural reflex of decerebrate rigidity and that of Liddell and Sherrington (84) on the myotatic reflex furnish the basis for present knowledge of postural control. Other contributions have been added, perhaps most notably by Magnus (92-95) and by Magnus and de Kleijn (96, 97) with reference to modifications in the midbrain preparation and also to labyrinthine influences.

The walking reflex—which is obviously concerned in static equilibrium as well as in the present study of equilibrium—is considered as made up of two essential forces, the one static and the other dynamic. Langworthy (83) states that "a tonic contraction of the extensor musculature counteracts the force of gravity and supports the body from the ground while alternate rhythmic movements of the extremities produce a change of position and are responsible for locomotion." To quote Sherrington (137), "the execution of stepping movements by the limbs does not of course in itself amount to walking. For this latter act the reflex stepping of the limbs has to be combined with reflex maintenance of the erect posture of the body."

Sherrington has shown the rhythmic tendency to be a property of the isolated spinal cord and the postural reflex to result in the decerebrate preparation, since, after cutting off inhibition influences of the cerebrum, the anti-gravity reflex becomes accentuated. However, although the spinal animal shows the rhythmic

stepping reflex, yet a normal control of the activity through the brain also exists. It is the belief of Langworthy that "the evolution of motor centers in the forebrain and particularly in the cerebral cortex undoubtedly plays an increasing part in the regulation of the rhythmic beat in higher animals." Evidence goes to show that the cerebral cortex as well as other not yet localized parts of forebrain and midbrain participate in normal control of the postural reflex.

As to the source of stimulus maintaining the postural reflex, Liddell and Sherrington (84) have traced these centrifugal influences on back to the proprioceptors of the same muscles which exhibit the tonic contraction. The unitary functional character of this proprioceptive reflex is shown in local modifications of plasticity of a highly sensitive and delicate kind, which the investigators describe as the myotatic reflex.

It is not, of course, to be inferred that there are not afferent influences from other sources which also modify the postural reflex. Magnus (93-95) terms the sum of the decerebrate postural reflexes as the "standing reflex." Additional influences shown in the midbrain preparation he calls "position or righting reflexes." He classifies the midbrain reflexes into five groups according to their source and the muscles upon which they act:

1. Optic (probably retinal righting reflexes)
2. Labyrinthine righting reflexes
3. Righting reflexes arising in the deep tissues of the body wall and acting on the head
4. Body righting reflexes arising in deep structures of the neck and acting on trunk and limb muscles

5. Body righting reflexes arising in deep muscles of the body wall and acting upon limb and trunk muscles

Magnus also groups these influences as (1) labyrinthine; (2) proprioceptive; (3) exteroceptive (chiefly pressure), and (4) influences from teleoceptors (eye, ear, nose).

Evidence with regard to connecting pathways is admittedly lacking in clarity. Almost all parts of the central nervous system, it appears, participate in the function of tonic control.

Magnus (95) gives an exceedingly clear summary of the practical method of functioning of the righting reflexes. His description here is particularly applicable to the character of activity on the balancing-board as used in the present study:

> "The whole righting apparatus with the only exception of the cortical centers for the optical righting reflexes is arranged sub-cortically in the brain stem and in this way made independent of direct voluntary influences. The attitudinal as well as the righting reactions are involuntary. If under the influence of cortical impulses the normal position of the body be disturbed, the brain stem apparatus is ready to restore it, so that every new cortical action finds the body in a normal starting position without previous voluntary effort. . . . Every sensory impression before being transferred to the cortex cerebri, has already acquired a certain special condition (local sign) depending on the previous righting functions acting upon the whole body or parts of it."

In spite of the emphasis given to labyrinthine influences by the work of Magnus and de Kleijn, of Schaltenbrand (132, 133), and of Landau (82), all of whom used "adequate" stimuli, posings of the head

in relation to the direction of the force of gravity, some opinion seems to minimize the effectiveness of labyrinthine stimulation in the human being. Experiences of aviators flying in a cloud and so lacking assistance of optic righting reflexes are commonly quoted. Evans (30) on this point makes the statement: "The higher an animal is in the scale, the less important and the more readily dispensed with are its labyrinth postural reflexes."

The preceding discussion of studies concerning equilibration shows it to involve a highly integrated and sensitive activity. Efficient functioning of such an activity may well be associated with optimum chemical balance of the cellular structure of muscle tissues. For this reason, a test which depends upon the child's ability to maintain equilibrium appears potentially of value in an investigation of relationships between motor efficiency and nutrition. Miles has expressed belief in the reliability of a test of static equilibrium as a measure of neuromuscular condition related to nutritional changes. Whether or not the "fatigue posture" clinically accepted as a classical accompaniment of malnourishment in children may constitute some functional evidence of chemical imbalance and whether or not this general atony may bear a relationship to the efficiency of the postural and the myotatic reflexes are now only matters of conjecture. Sufficiently delicate methods of measuring the contributing factors have not been devised. Neither have methods of approach been planned to throw various factors successively into clear relief. How to ap-

proximate a "zero condition" in human experimentation of this character remains perhaps the most difficult problem of all. However, *in toto,* and also particularly perhaps in the use of studies of equilibrium, an apparently fruitful field of investigation is presented.

The devising of tests of equilibration suitable for use with children offers practical difficulties. Obviously, the ataxiameter is unadapted for such purposes both because of lack of intrinsic motivation and because of the strain involved in inhibition. A test of a more dynamic character emphasizing the statokinetic reflexes in reactions to partial body movements seems more nearly indicated for children. Johnson (76) has devised a walking-board which tests ability in progressive movement. This is highly interesting to children and utilizes a natural activity of a kind related to the field here to be investigated. This board was first used in a series of tests previous to 1921. In the work reported by Hunt, Johnson, and Lincoln (73), a detailed description with method of scoring is given. Succeeding experimentation has resulted in distinct modifications which are described by Courtney and Johnson (23) in 1930. The data presented indicate that the walking-board is a promising measure of individual differences in body movements. It also affords opportunity for study of emotional responses. Baldwin (5) used a modification of the Johnson walking-board. He concludes that such a test is probably highly correlated with maturity and general motor development.

For the present purpose a highly motivated stato-

kinetic activity is seemingly desirable. It should involve some difficulty in coordination but only up to such a point as not to disturb motivation. The principle of the seesaw is time honored in its qualities of intrinsic intrigue for young children. On this basis, therefore, the balancing-board is developed and used in the present study.

From the previous analysis it is assumed that the following factors are among those contributing to skill of performance on the balancing-board: (1) age; (2) sex; (3) height and weight; (4) position and distance of feet; (5) footwear; (6) respiration and heart beat; (7) motivation; (8) intelligence; (9) socio-economic status of family; (10) control of attention; (11) eye fixation; (12) vestibular stimulation (probably at a minimum); (13) visual spatial perception including influences of eye muscles; (14) proprioceptive reflexes initiated in muscles, tendons, and joints; (15) physiological condition; and (16) chemical balance of muscle cells.

II

THE EXPERIMENTAL GROUP

Five boys and five girls are used as reactors. Eight children have been in the nursery school more than one year. All are accustomed to laboratory equipment and to varied laboratory tests. The members of this group, designated by the alphabetical letters A to J, were all born in 1925. At the beginning of the learning series the oldest was 2 weeks past 5 years. The youngest was 4 years and 3 months old. All are of native-born parentage except for one mother. The group shows an average intelligence quotient (Stanford-Binet) of 114. The highest intelligence quotient represented is 145; one is included below 105.

Individual weights range close around the normal average (Woodbury tables). Six are above the determined average. One exactly equals it. Three are below the norm of the tables, but show only small percentage deficiencies, the lowest 6.6 per cent. No special nutritional problems are evident. The children are without exception reported as enjoying food.

The socio-economic group represented approximates the highest level.

A scattered selection of older reactors is also used. A man, Reactor X, 23 years old, and a woman, Reactor Y, of 20 years, both of excellent muscular build and unusual skill in the various sports, are subjects for the adult comparisons. A girl, Reactor O, 11 years and

10 months old; a boy, Reactor N, 8 years old; and a boy, Reactor M, of 6 years and 2 months, all as computed at the beginning of the test, are used to secure some indication as to age differences in ability in balancing.

III

DESCRIPTION OF APPARATUS AND METHOD

A. Apparatus

The test of equilibrium consists of a board (*BB*), 18 inches square, which balances freely over a fixed steel rod (*A*), 3/4 inch in diameter, as an axis. This board, 3/4 inch in thickness, is held on the rod at each end by a steel T-pipe, the nipple of the T-pipe fitting into a flange on the board. Lateral movement of the T-pipes on the rod is prevented by a collar fitted on the rod at the inner end of each T. The steel rod is

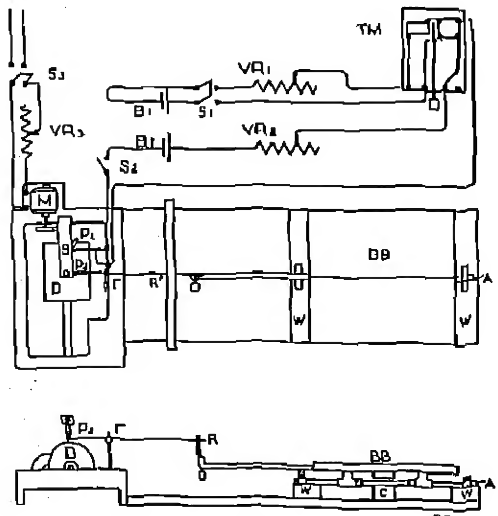


FIGURE I

Wiring Diagram and Profile of Apparatus for Testing Equilibrium

supported and held fixed by two table clamps set 20 inches apart on a firm wooden base (*W*).

A wooden brace, 2 inches wide and 2 inches thick, is fastened across the middle of the under surface of the balancing-board (*BB*), crosswise to the axis. On the wooden base immediately below each end of this brace and parallel to it is fastened a 6-inch length of wood (*C*), 4 inches wide and 4 inches thick, which constitutes a stop to the excursion of the balancing-board. Each of these lower wooden stops is surmounted by a large rubber heel plate set on its extreme outer top surface. The rubber thus placed at the contact point between the descending balancing-board (*BB*) and the wooden stop (*C*) below serves to lessen vibration effect upon the recording apparatus and also reduces the force of the impact to the reactor. The maximum excursion of the balancing-board at its extreme outer edge—that is, the distance from the end of the wooden brace to the stop when that side of the board is tilted up to its greatest height—is approximately 4 1/4 inches. The total angle subtended is 28 degrees, half of which is below and half above the point of equilibrium of the balancing-board.

A small steel tubing, 17 1/2 inches long and 5/8 inch in diameter, is secured firmly to the middle of one end of the balancing-board, parallel to the axis. To the outer end of this tube is fixed at right angles an upright piece of the same, 12 inches long, thus forming a crank operated by the movement of the balancing-board. The longitudinal half of the perpendicular part is cut away for 5 inches from its upper end, and a small hole is

drilled through this upright piece 8 inches above the right-angle joint.

Through the aperture in the metal crank extends a light steel rod (R), free to slide back and forth, and carrying at its outer end a metal guide in which rides the point of a stylographic pen (P_2) over a recording kymographic drum (D) using a continuous paper record. The upper end of the pen rests in a suitable support (S). The metal rod (R), at a point 3 1/2 inches from the pen (P_2) and 15 3/4 inches from the crank (O) when the board is at equilibrium, is supported on point bearings which act as a fulcrum between crank and pen. The delicate adjustment makes it possible for the slightest movement of the balancing-board (BB) to produce a prompt response from the recording pen (P_2). When the board is down, i.e., contacting the rubber shock absorber, on the left side, the pen makes its greatest excursion to the right, and vice versa. When the balancing-board is held level, the pen rides straight in the center of the distance between the limits of its possible excursion to either side.

The kymograph is driven by a motor (M) operating on a 110-volt, alternating current, a rheostat (VR_3) being used to regulate the speed. A Harvard clock (TM), supplied by four dry cells, governs the interval of a 5-second time line produced by an electromagnetic pen (P_1) which has current source in a 6-volt storage battery (B_2). The electrical connections of the entire piece of apparatus are shown in the accompanying diagram, Figure 1.

A screen, 52 inches high, is mounted between the re-

cording apparatus and the balancing-board to shut off the mechanism of the kymograph from the reactor's field of vision.

For that part of the experimental series which is planned to include some control of visual aids, a visual indicator is added to the described apparatus. A wooden extension, consisting of an arrow 27 1/2 inches long with a pointed metal tip, is affixed to the crank. Being thus attached, the arrow in its described arc makes a change corresponding to every movement of the balancing-board. The tip of the arrow, which is 37 1/2 inches above the level of the balancing-board and 16 3/4 inches from its nearest edge, is placed at a height and distance convenient for fixation by children of the age group used. It subtends an angle of 28 degrees. The point of the arrow moves across a white cardboard background on which are drawn in bold black lines two concentric curves, 7 inches apart, corresponding to the arc described by the arrow. Across the center of the band thus formed, and bisecting the arc, is painted a perpendicular line surmounted above the band by an arrow head. Perpendicular line and culminating arrow head are of a bright red color. The metal arrow point of the wooden extension from the crank coincides with the red line on the background when the balancing-board is held at equilibrium, thus forming a visual indicator of perfect balance and also of its approximation. The outer quadrants of the arc are painted black, leaving the middle half white except as bisected by the perpendicular red line indicating equilibrium.

In that part of the series which directed the attention of the child to an equalization of the distance of his two feet from the center line of the balancing-board, a half-inch strip of white celluloid was fastened the length of the board over the axis.

B. Procedure

The method of procedure in a practice period on the equilibrium board is based on findings from two reactors outside the experimental group who were used to test out the apparatus. The aim is to give a period of sufficient length to have definite practice value but not so long as to be unduly fatiguing or boresome to young children. The breaking of a single activity period by short rest intervals seems to give the most satisfactory results in performance and also to prevent the undesirable reactions. A practice period is therefore used which consists of six work periods of 30 seconds each, separated by rest intervals of 45 seconds each. Hereafter, the phrase "work period" is used to indicate the 30 seconds of uninterrupted activity; "rest interval," the 45-second intermission between work periods; and "practice period," the total of the six work periods and five rest intervals.

The child is invited by the experimenter to play a seesaw game. He is brought into the experimental room and shown the balancing-board. The experimenter, while standing on the board, demonstrates how it inclines from one side to the other over the longitudinal axis. The reactor is shown, however, that with

effort the board can be held approximately level for a short time. The majority of children five years old are eager, after a very brief demonstration, to try to hold the board level. Though the child of five years probably has an interest in simply tilting from side to side on such a balancing-device, yet the reactors in this group appear readily to understand the purpose of the activity as directed toward holding the board at equilibrium and to strive with varying but, on the whole, considerable earnestness and zest toward this end.

The position of the child on the board is uniform with reference to the direction in which he faces and approximately so with reference to his relation to the axis. He faces the intercepting curtain and the recording apparatus near which the experimenter stands. This position, facing these elements, enables the reactor to direct his glance at will toward the mechanical parts or the experimenter without turning the head and, consequently, with the minimum disturbance of bodily equilibrium. One foot is set on each side of, and approximately parallel to, the axis. In the earlier series, the reactor is allowed to explore freely with his feet, to choose a wider or a narrower stance, and also, if he wishes, to place one foot at a greater distance than the other from the axis line. The only requirement made at the beginning is that the feet be so placed that the reactor faces the kymograph. It is believed that in this particular skill such a free method may facilitate learning and that gradually there will emerge in the case of each individual a more or less constant and characteristic response pattern. In a later series the

axis line is emphasized by a white stripe, and the child is at each work period instructed to place his feet the same distance from the white line. If necessary, he is given assistance.

When the child is in position on the balancing-board, the following instructions are given:

> "Now hold the board level. Try hard to hold it level. Don't let it tip this way. [Experimenter holds board slanting in one direction.] And don't let it tip this way. [Experimenter holds board slanting in the other direction.] Hold it level like this. [Experimenter holds board in position of equilibrium with child on it.] Begin when I say 'Go!' Keep trying. Don't stop till I say 'Stop!'"

A warning signal "Ready" is used. Approximately 2 seconds later the switch starting the recording kymograph is thrown, the signal "Go!" is given, and the stop-watch is started. At the end of the 30-second work period, during which the reactor is in continuous activity attempting to hold the board in equilibrium, the signal "Stop!" is pronounced. The reactor steps off the board, stands at ease, walks about, or, as in the case of these children, plays with marbles or blocks, or busies himself quietly at whatever in the room may engage his attention. The 45-second rest interval is succeeded by another 30-second work period, and so on, alternating work period and rest interval until the six work periods which make up a total practice period have been completed. This aggregates 3 minutes of work for an entire practice period, requiring a minimum of 6 3/4 minutes.

Every effort is made to insure the child's understanding of the directions in the belief that the maximum

control and uniformity with regard to comprehension of terminology and of directions are necessary in order to place in clear relief the factor of skill in equilibrium, which is the point of the test. These directions are greatly abbreviated with each successive trial, as the reactors show further repetition to be superfluous. After a few trials, only the warning, the starting and the stop signals are usually necessary, except when some variation in the series is introduced.

Figure 2 shows a reproduction of a record of a single work period. The record uses a strip of paper 3 1/2

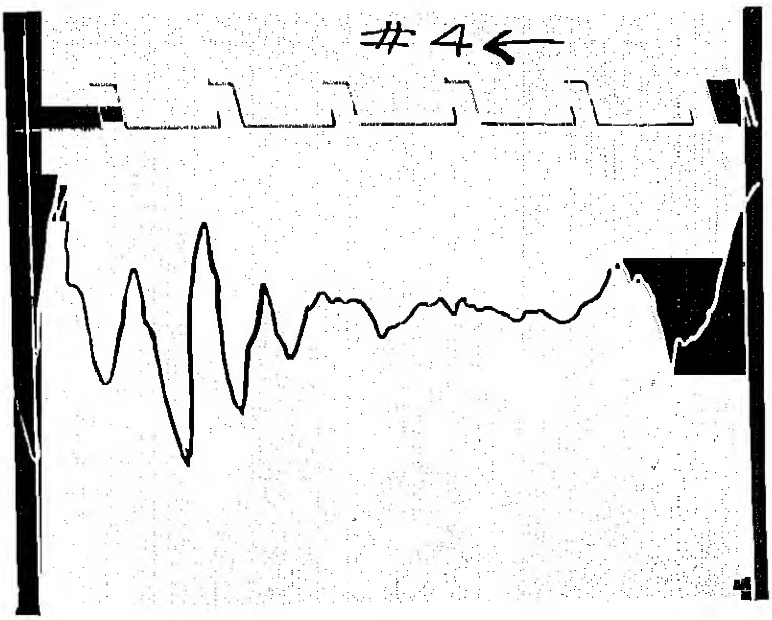


FIGURE 2

A KYMOGRAPHIC RECORD TRACED IN THE TEST OF EQUILIBRIUM
Record of performance for 30 seconds, one work period of the six work periods composing one trial, is shown.

inches wide and approximately 1 yard long, variability in length being due to the warming-up of the motor. Identification data of name, date, time of day, and direction in which the reactor is facing are recorded. The six successive short work periods are indicated by number and for convenience are included on a single strip of paper. Other characteristic data regarding foot position, bodily posture, types of activity, facial contortions, and other extraneous movements, as well as introspections or significant remarks, are recorded as informal notes along the record strip.

C. Method of Scoring

The record strip used in the equilibrium test shows the variable crosswise excursions of the stylographic pen back and forth between its fixed limits. For scoring, two parallel lines are first drawn, one marking the left and the other the right outer limit of the recorded excursion. The distance between these outer limits is then bisected by a line which divides the record longitudinally into two equal, contiguous rectangles. A planimeter is used to measure the area of the plane surface as outlined by the recording pen on either side of the bisecting midline of equilibrium. Of necessity each side is measured separately. A record of ideally perfect equilibrium can show only a straight line exactly following the path of the bisecting midline, the inner boundary of the two contiguous rectangles. Such a record obviously can give no area on either side of the midline and may be stated as

representing a zero percentage of that area possible to be transversed on either side. On the other hand, the poorest record possible of execution can show only a line following the three outer boundaries of either contiguous rectangle. This completed area as measured by the planimeter must exactly equal the area of the constructed rectangle on either side, or it may be phrased that the traversed area of the poorest record equals 100 per cent of the possible area. Thus, the record of performance can be translated into a percentage score, increased proficiency in balancing being indicated by an increasingly smaller percentage. This percentage, for the left rectangle, for example, represents the ratio of the area actually recorded on that side by the pen to the maximum area possible to be recorded there. The percentage for either side of the record is a numerical score indicative of the relative time spent by the reactor in balancing on the opposite side of the axis and signifying the proficiency of performance during that time. The percentage representing the achievement on each side of the axis for the best 25 seconds of every 30-second work period is tabulated, as is also the average percentage representing the total performance of the reactor for that time. These three items, left, right, and average percentage, are totaled for each of the six work intervals and again averaged to make a 3-item score for a complete practice period. This score thus shows average performance on the left and on the right side of the axis and also total average achievement.

D. Program of Experimental Series and Theoretical Implications of the Variations

The test of equilibrium is concerned with an exceedingly fine type of motor coordination which brings into play a delicate adjustment of practically every body part. For this reason a long period of training is necessary, and a somewhat prolonged learning series is planned. This includes the following variations:

1. An initial practice series in simply holding the board in equilibrium.
2. A short series in which attention is directed to the most advantageous placing of the feet. One observation of expert balancing is given here.
3. Training in the use of visual cues by the addition of a visual indicator.
4. A short control series duplicating the procedure of the first series.
5. An additional short blindfold series and a control for a very small group.
6. A short retention series after a 3-month interval for a few selected individuals.

The introductory practice series comprises 20 practice periods in which the reactor's attention is directed simply toward balancing on the board while facing in the prescribed direction. A minimum of direction or suggestion as to any contributing feature is given in order that the reactor may explore freely and develop his own most satisfactory pattern of response.

The second series of 5 practice periods attempts some training with reference to the important factor of

foot position. A white stripe is placed longitudinally, coinciding with the mid-axis line. The reactor is carefully and repeatedly instructed, and assisted when necessary, to place his feet at an equal distance on each side of this white line. Just previous to the second period of this series the children are allowed to observe for 30 seconds the expert performance of a man who is unusually proficient on the balancing-board.

The third series, consisting of 10 practice periods, adds to the training in foot position an attempt at some control of, and training in, the use of visual aids. The mid-axis stripe and the instruction as to foot position are continued. The upright arrow oscillating across the 28-degree arc, as previously described, is used as a means of directing attention to visual cues and forms a visual indicator. The belief is that such a visual indicator may serve several purposes. First, it provides a prominent set of visual cues at approximately the level of the eyes. Visual cues most used formerly are apparently those centering around the crank over the axis rod at a point near the board. Observation of these necessitates some bending of head and trunk, which is obviously disturbing to equilibrium. This bending of the body is eliminated by the use of the perpendicular arrow. The second point is tied up with some assumed differences in the stimulus pattern of the child and of the adult. Adults apparently give much more attention to visual cues than do children of five years. Can the child of this age be given such specific training in the use of visual cues as to cause him to show any marked improvement in balancing-

performance? The third purpose centers around attention. It is believed that the added interest in the significance of the arrow when held in its perpendicular position against the segmented arc may serve to focus attention and to increase integration, thus producing a better performance. The attempt is thus made to reinforce the child's kinaesthetic perception pattern by an observed and meaningful objective indication of his achievement.

The control series, consisting of 5 practice periods, gives a basis of comparison both with initial achievement unaffected by special variations of method and with the data of the variant series.

The short blindfold series of 3 practice periods is used with three highly cooperative 5-year-old children who especially enjoyed this part of the program. With the two adults 10 blindfold trials were allowed. There appears to be some significance in a series cutting off all visual cues just following a time when special emphasis has been laid upon them. Also, it is desirable to secure some information as to the relative dependence of the child and of the adult upon visual aids as compared with kinaesthetic and muscle and joint sensations. The series is followed by one control practice period identical in procedure with the initial series and with the other longer control series.

A retention series including 5 practice periods, which duplicates in method the original practice series, is given to three reactors: A, from the 5-year-old group; X, an adult; and L, 12 years old. This series is conducted approximately three months subsequent to the

completion of all the other series, during which time there has been no practice whatever on this test or on anything approximating it.

The program of the series as arranged for the adults and for the intermediate age levels is abbreviated in such a way as to furnish comparable data on certain desired points only. All age levels began with the same initial practice series in simply holding the board level with the accompaniment of the minimum of instruction or suggestion. This uniformity in the first series gives opportunity for comparison of initial ability, initial speed of learning, and early postural patterns. The adults are given 24 instead of 20 practice periods in this series since they seem still to be making improvement. The use of the white mid-axis line, the one observation of a proficient performer, and the arrow indicator are used only for the 5-year-old group, since such training and instruction seem superfluous for the other reactors. The older subjects are fully conscious of the contributory factors dealt with in the variant series and are voluntarily striving in each practice period to find the most advantageous use of these various aids. Both the 5-year-old children and the adults, however, are given the blindfold series in an attempt to bring out any differences in the stimulus patterns utilized by children and by adults. Also, the same series is given to members of three age groups in order to test retention of skill in a broader age range and with a higher degree of reliability. The series for the intermediate ages are shorter and are included as a means for some further comparison of initial

ability and of initial speed of learning on an age basis.

The distribution of the practice periods as to time sequence is uniform. A Monday, Wednesday, Friday schedule is followed throughout except as absence or other unavoidable occurrence lengthens the interval, or as, toward the end of the program, it is found necessary in a few instances to shorten the intervening time.

E. Motivation of Performance

The balancing-board, as used in the test of equilibrium here discussed, provides a very difficult form of activity. Highly integrated and earnest effort on it produces some fatigue. Also, boredom may easily be added to the difficulties of the less skilful performer. The children come to the first practice periods with much zest and many expressions of joy. However, it involves hard work, and in the course of a somewhat prolonged learning experiment there is danger that this element may gradually make the test more and more disagreeable to the child. For this reason strong positive suggestion is used in every way possible; it is a "good balancing game"; "we had lots of fun balancing yesterday"; "you have only two more chances"; these and similar statements are used throughout, with variations, as propaganda for perpetuating a strong interest on the part of the child.

However, the test possesses an intrinsic motivation of an unusually fine type which furnishes the real spur to continued and earnest effort. The child's pleasure in a momentary success in holding the board at equilibrium is easily observable, and every success, even

though small, is given approval by the experimenter. Improvement, too, from day to day can usually be recognized by the reactor. The sense of achievement resulting from these two factors of momentary success and steady improvement appears to furnish a strong and abiding motivation, sufficient with very few aids to carry the reactor through a long learning series with a steady and dependable enthusiasm.

Blocks are used as the chief form of extrinsic reward. The child, after making a "good" record, is allowed to choose a block from a varied assortment and to carry it back with him to deposit in a special box in the nursery school. The fact that the child cannot himself definitely observe and rate his achievement as in the aiming test is a disadvantage. However, this difficulty is partly obviated by the child's recognition of and pleasure in a momentary successful balancing. Also, after such successes in holding the board in equilibrium, the reactors are frequently shown the "good marks" which they have made on the record.

Just following the long initial series, at a time when enthusiasm might be expected to flag, the children are permitted singly to observe the expert balancing performance of a highly proficient man. The belief is that such an observation aids motivation in that some attribute analogous to prestige is associated with the playing of the game by the fact that a grown man, whom they all like very much, enjoys the game and is skilful in it.

Toward the end of the entire experiment, in a special endeavor to secure the best possible achievement of

which the child is capable, a balloon is used for additional motivation. After every "good" work period in a practice period, the child is permitted to play with the balloon instead of with the blocks or marbles regularly used in the relaxation interval.

No special form of motivation is used with the adults or with any children except the 5-year-old group. A slight element of competition is present, but the chief incentive to the excellent and sustained effort put forth is the pride and pleasure in achievement. The test involves a physical performance which to children above six years—and to many adults—seems to be fascinating. The oldest reactor designates it "good sport."

IV

RESULTS

A summary of the total achievement and of the individual differences in the scores of eight children and two adults in the equilibration test is shown in the graphs, Figure 3 (*a* and *b*). On the basis of so small a number of reactors the results cannot be assumed in any way to be conclusive. However, a learning series of considerable length has been carried through by each reactor. In the course of the program and particularly with reference to the variations introduced, certain tendencies appear which seem significant and which may have tentative value with reference to the planning of programs and techniques for further research.

The graphs evidence a slow learning process with a seeming absence of the usual rapid initial gain. Individual differences are shown, and also certain general tendencies—in so far as may be inferred from the data at hand—appear to be present.

A. Age Differences

The graph mentioned above portrays age differences as shown throughout the experimental program.

Those differences which are related to variations in the series are discussed in connection with the analysis of the specific variation with which they are associated. Table 3 shows what may be termed "initial" age differentiation. The scores on trial 5 rather than on trial

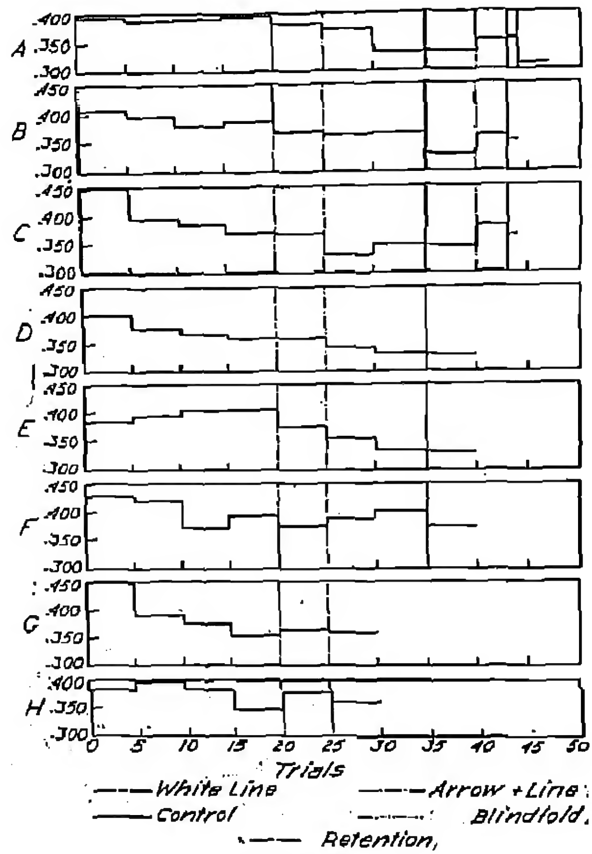


FIGURE 3*a*

GRAPH SHOWING INDIVIDUAL PERFORMANCE OF CHILDREN THROUGHOUT THE VARIATIONS OF THE LEARNING PROGRAM IN EQUILIBRIUM

1 are used as being probably more truly representative of the child's ability in equilibrium. The young child obviously experiences greater difficulty than the adult in comprehending just what is expected of him in a test

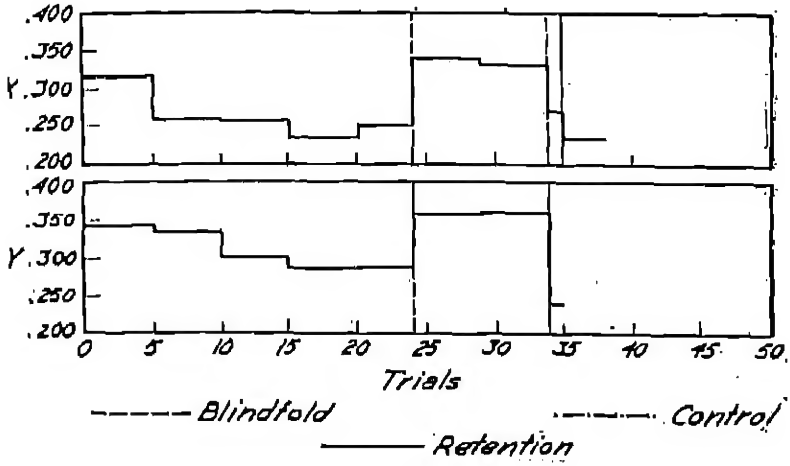


FIGURE 3b

GRAPH SHOWING INDIVIDUAL PERFORMANCE OF ADULTS THROUGHOUT THE VARIATIONS OF A LEARNING PROGRAM IN EQUILIBRIUM

situation. He is also more subject to slight fears and to inhibitions caused by unfamiliarity. In the early records such influences may tend to mask the ability in equilibrium. The fifth record is used as representing a more nearly comparable measure of "initial" skill in body balance.

The average of the six 30-second work periods which make up one trial show an unmistakable increase in equilibrium from the mean age of 4 years and 8 months to the age of 23 years. Total increase between the average of the records of the 10 young children and the record of the 23-year-old man is 13.9 per cent. This figure means that, as measured by the present test, that proportion, 13.9 per cent, of the advance from total lack of equilibrium to ideally perfect equilibrium is

TABLE 3

INITIAL AGE DIFFERENTIATION IN EQUILIBRIUM ON BASIS OF TRIAL 5

Reactor	Sex	Age	Mean of six 30" work periods Left	Right	Average	Percentage increase over next lower age level	Best single 30" work period Left	Right	Average	Percentage increase over next lower age level
H	F	4:5	.305	.398	.351		.246	.350	.296	
D	F	4:9	.424	.313	.369		.263	.377	.321	
E	F	4:9	.283	.502	.393		.269	.459	.366	
F	F	4:4	.373	.482	.428		.352	.428	.390	
I	F	4:10	.376	.500	.438		.330	.505	.417	
Mean	F	4:7	.352	.439	.396		.292	.424	.358	
A	M	5:0	.444	.294	.369		.185	.314	.250	
B	M	4:5	.385	.403	.394		.338	.338	.338	
J	M	5:1	.416	.401	.408		.265	.514	.389	
G	M	4:5	.395	.445	.421		.431	.361	.396	
C	M	4:10	.498	.383	.441		.530	.294	.411	
Mean	M	4:9	.427	.385	.407		.349	.364	.357	
Mean	M&F	4:8	.389	.412	.401		.321	.394	.357	
M	M	6:2	.467	.321	.394	.007	.419	.269	.344	.015
N	M	8:0	.305	.275	.289	.105	.292	.231	.261	.083
O	F	11:10	.257	.296	.276	.013	.215	.292	.254	.007
Y	F	20:0	.275	.299	.288	—.012	.225	.238	.231	.023
X	M	25:0	.238	.289	.262	.014	.178	.229	.203	.051

made between the mean age of 4 years 8 months and 23 years.

However, the difference between the adult and the best child, a girl 4 years and 5 months old, is only 8.9 per cent. A similar comparison with the poorest child, a boy 4 years and 10 months old, shows a difference of 17.9 per cent. The group of children thus is seen to cover within itself a range of 9 per cent in difference in efficiency as regards equilibrium.

The mere fact of increase in body balance with age up to young adult life is obvious. However, an examination of the percentage increase on each of the levels tested shows a strikingly large proportion of the gain to occur between the ages of 6 and 8 years. This may be due to a chance distortion inherent in the selection of the few cases examined. Reactor N, the 8-year-old, has no history of special training or ability of this character. He comes from a home of much lower socio-economic level than the 5-year-old group. His motivation was excellent. He enjoyed each trial keenly and apparently considered it a special privilege to join in an experiment. He left his play with the other boys on the street quite readily when his turn came "to balance." However, N's motivation did not appear to be stronger than that of M, younger, or of O, the 12-year-old girl. An attitude of keen enjoyment was characteristic of all three.

Trial 5 happens to light on one of reactor N's better records, though it is not extraordinarily so. His trial-10 record averages .302 with a 30-second period in it better than the best in this trial-5 record. The trial-11

record averages the same as the trial-5. Total percentage of gain between his first and fifth trials is large, .124 as, however, against a gain of .122 by reactor O in the same time.

It may be contended that the best single 30-second work period of the six composing any one trial is a better criterion of the reactor's absolute ability. In general, averages appear to offer the safer and more nearly accurate basis of comparison. However, in this instance, where a single trial is designated as a means for showing age differentiation, the record of the best single work period may possess advantages. Perhaps the best short period is significant of the fundamental ability of the organism as least affected by extraneous influences.

Data of the best single 30-second work period of trial 5 for each reactor are included in the table. The successive percentage gains from one age level to a higher again show the definite progression in ability from the five-year to the adult stage. On this basis the total gain from mean age 4:8 years to 23 years is 13.4 per cent. Difference between the best child, a boy 5 years old, and the adult is decreased to 4.7 per cent. The extraordinarily good 30-second record, which makes this very low difference, comes from Reactor A, a 5-year-old boy. It represents an anomaly of the kind to lead to distrust of comparisons based on "single best" records rather than the more dependable averages. Evidently, for one short period in his fifth trial, an unusually fortuitous aggregation of favorable circumstances combined to produce a .250 score which

is not again equalled until his thirtieth trial. A single best score equalling or exceeding this is found only 3 times in the 47 trials of this reactor, who, in the general comparisons, ranks in the lower half of the group of children.

Difference between record of the poorest child and of the adult is 21.4 per cent by the "best single" method of scoring.

A similar unusually large gain between the years of 6 and 8 is shown also by these records although the amount is slightly reduced here. However, 8.3 per cent as a two-year gain remains as a clearly large proportion of the total increment of 13.4 per cent in approximately 18 years.

This second method of comparison also brings out a greater increase, 4.4 per cent, between the 12-year and the adult level. This indication may or may not be in accord with the fact.

Other age differences also appear. Table 4 shows the mean for 24 trials each of 8 children and 2 adults. The man's mean score shows 11.9 per cent greater efficiency in this test than the mean of the 5-year-old children. The woman's mean score is 6.9 per cent better than that of the children. In percentage of absolute gain in power of equilibrium during the 24 trials, by Table 4 the children show a mean gain of 4.2 per cent as against 6.7-per-cent gain by the man and 4.2-per-cent gain by the woman. It is to be noted, however, that individual children made a gain of 6.3 per cent and 5.3 per cent.

In summarizing, it may be stated that the data at

TABLE 4

MEANS AND PERCENTAGE GAIN FOR LEARNING SERIES IN EQUILIBRIUM

Reactor	Sex	Trial	IQ	Height	Weight	Left	Right	Average	Percentage gain in 24 trials	Left-right
D	F	24	115	43.5	41.5	.4514	.2843	.368	.024	.1671
H	F	24	116	43.2	42.5	.3656	.3849	.375	.053	—.0193
E	F	24	105	42.5	42.6	.3896	.3953	.392	.049	—.0057
F	F	24	110	43.7	43.7	.4438	.3546	.399	.049	.0893
Mean	F	24	111	43.2	42.6	.4126	.3548	.3835	.0437	.0576
G	M	24	121	40.7	42.5	.4104	.3409	.376	.035	.0595
C	M	24	87	49.7	45.5	.4014	.3619	.382	.063	.0395
B	M	24	113	44.2	48.7	.4034	.3610	.383	.033	.0424
A	M	24	145	45.8	45.0	.4158	.3633	.390	.027	.0525
Mean	M	24	116	45.1	45.4	.4077	.3568	.3827	.0395	.0509
Mean	F&M	24	113	44.1	44.0	.4101	.3558	.383	.0416	.0543
Adults										
X	M	24				.2663	.2629	.2643	.067	.0034
Y	F	24				.2823	.3461	.3143	.045	—.0638

hand indicate a slow, somewhat irregular increase of skill in equilibrium with age. The curve seems to show a much more rapid rise between the ages of 6 and 8 years. Furthermore, adults probably make a somewhat greater percentage gain in the course of 24 trials than children of mean age 4 years and 8 months.

B. Sex Differences

Table 4 is arranged to present sex differences in body balance as shown by the means of 24 comparable trials on the balancing-board by 4 girls and 4 boys of mean age 4 years and 8 months. Girls average .3835 and boys .3827, thus showing almost exact equality in mean efficiency on the 24 trials. Girls show the best and the poorest scores by these averages, though in each instance this is a matter of only about 1 per cent difference from the best and the poorest boy's scores.

Girls gained an average of .4 per cent more than boys throughout this series of 24 trials, a difference which is obviously insignificant.

There is no reason to suspect that this particular sampling contains girls of especially greater ability or boys of less ability. The two groups are considered to be quite evenly matched and to show a rather exceptional physical and mental status. Mean age of girls is 4:7, of boys, 4:9, showing a slight difference in favor of boys. Mean IQ of boys shows a superiority of 5 points over the girls. Such a difference, however, is probably to be considered negligible in so small a number of cases.

Comparison made on the basis of the average at-

tained in the highest trial score of the 24 gives the girls an average of .340 as against .349 for the boys, a superiority of less than 1 per cent for the boys.

Data at hand from the present experiment using the balancing-board clearly indicate no material difference in the efficiency of performance by the two sexes at the mean age of 4 years and 8 months. The evidence here is in disagreement with reports from tests of static equilibrium as given by Hancock (46) to children 5 to 7 years old and by Hinsdale (61) to boys and girls of 7 to 13 years. Both of these investigators have found a greater steadiness in girls, stated by Hinsdale to amount to about a 10-per-cent difference. Present results do accord, however, with Miles's (118) data of ataxiameter records which go to show that average results for adults of both sexes agree closely, as that investigator states, "the disadvantage of the greater height of men being counterbalanced by their larger standing base."

Tests of two adults, however, on the balancing-board show superiority of performance in the male practically throughout, though various influencing factors as well as the comparison of only the two cases make this difference of probably negligible significance. Records of the man exceed those of the woman by 5 per cent, on the average, for 24 trials, by 2.2 per cent in absolute gain in the same series, by 2.7 per cent on initial rating, and by 4.9 per cent on final rating.

The woman's footwear may influence her performance sufficiently to produce the differences reported in this comparison. Miles (118) believes the accus-

tomed footwear gives more nearly consistent results in ataxiameter tests. No attempt was made to control this factor. However, in the course of an extended learning series a woman may wear a half dozen different pairs of shoes of varying last and with considerable range in heel height. In the same time a man often wears only one or two pairs of shoes, and those similar in last and heel. Reactor Y reported a necessity for slight changes of body adaptation to the test occasioned by a change of shoes. Change in the support of the arch was more noticeable to her than change in heel height itself. The 12-year-old girl, O, wore flat heels or tennis shoes except in the final retention series, where she registered a loss. Reactors Y and O showed a similar posture in balancing, in both cases characterized by a decided tilting-forward from the hips not observable in the young children or in the man. Whether or not in this difficult test such a postural variation constitutes a compensation associated with fundamental differences in the proportions of the adult female skeleton or whether it develops with the wearing of high heels, and, further, whether or not a compensation thus necessitated lowers efficiency of body balance is a matter of conjecture. For a reliable study of adult sex differences in body equilibrium as uninfluenced by extraneous factors, it is perhaps necessary to use women who have always worn lasts and heels of the golf-shoe type. Such a group, having never experienced the anterior-posterior shift in the center of gravity occasioned by the wearing of high heels, is

perhaps more truly representative of the female's ability in equilibrium.

To summarize, the data from a prolonged learning series on the balancing-board show no sex differences in young children. Adult differences favoring the male may be of negligible significance if extraneous influences are equalized.

C. Sidedness

In the present study of equilibrium, comparison of records for the right and the left side of the body involve several questions which render it difficult to separate and to designate the factors operative:

1. Does the reactor consistently prefer one side of the body, and, if so, tend to work more with that side? Does a tendency to work more with a preferred side throw the body weight more often to that side of the axis and thus increase the score on the preferred side?[2]
2. Is the preferred side more efficient than the other? If so, does this superior ability tend to decrease the score of the preferred side and so to counteract any effect of increase mentioned in question 1?
3. Is there a tendency for one side to carry the weight and for the other to act as a "feeler" working for the fine adjustment? Or does the weight-carrying side receive the greater momentary amount of stimulation and so act the more efficiently in delicate discrimination also? If the right is the preferred side,

[2]It is to be recalled that by the method of recording used, the smaller score indicates the better performance.

does it carry the weight or does it act for fine adjustment—or both?

4. Apparently the individual builds up a pattern of preferred responses with regard to sidedness in body balance. In comparison of individuals, is there a central tendency or a wide variation in these patterns of preferred response?

Obviously this one study and the meager amount of data presented cannot expect to solve the complicated problems of sidedness. The data on the 24 practice trials, as presented in Table 4, seem to offer the best approach here afforded. However, modification of sidedness by certain variations in the series is also noted.

In the comparison of the records of one side against the other, this fact must be kept in mind. A small record on one side may show greater efficiency of performance for that side, but it may also be produced partially by the fact that less time was spent on that side. In general, the smaller record on one side seems to be fairly closely related to a better performance by that side.

Averages of the 24 trials of each child show in six of eight children, all of whom are right-handed, a smaller score for the right than for the left side. In these six individuals, the excess of the left varies from 4 to 16.7 per cent. The group of boys shows variation of only 2 per cent. On the other hand, the girls show great difference in this respect. One girl, who scores highest of all the children on the 24 trials, has an excess of 16.7 per cent in the left-hand score. Two girls show a re-

versal, a small excess, 2 per cent and .6 per cent on the right. In the averages of the girls' scores and of the boys' scores, however, the individual differences disappear. Both show an excess in the left-hand score; the girls of 5.8 per cent, the boys of 5.1 per cent.

The two adults show wide variation in sidedness. Excess is on the left, .3 per cent, for the man and on the right, 6 per cent, for the woman. Both are right-handed. Both reactors are skilful workers on the balancing-board, Reactor X probably quite exceptional in his performance. On the basis of his record as to sidedness, it might be inferred that the best performers show little sidedness and that this quality may be a factor which makes for a high score in equilibration. However, D, holding consistently the highest record of performance among the children, shows an excess of 16.7 per cent on the left. It is entirely possible that the man's lack of evidence of sidedness indicates an individual characteristic. Although he is right-handed, he reports a left-handed performance with several tools, such as the axe, hoe, and broom.

It seems probable that great individual differences in sidedness occur even aside from the facts of handedness. Further experimentation is necessary to determine whether girls are more variable in sidedness than boys, whether better reactors show more or less sidedness, and whether adults exhibit this characteristic in equilibration more or less than children.

Another and somewhat more subtle tendency is noted by observation of actual performance, though it cannot always be traced in the numerical records. There

appears among the reactors in this experiment to be an individual preference for initiating effort to balance from a certain position and with one foot rather than the other. D, the best performer among the children, showed a very constant tendency to work with the left side of the board down and the right foot thus in the air. Notations of the extreme activity of this right foot are found throughout the series. These notations state observations such as "Moves right foot continuously—even up on toes," and "Left foot hardly ever moves." In her case, this habit of performance is directly traceable on the records. In conformity with the position down on left and up on right, the daily records show many more contacts for the left side, and the average score shows the large excess of 16.7 per cent for that side.

The boy B, also of the children's group, showed the same characteristics of extreme activity of the right foot, using the left foot in a lower position as a base. In some instances, this is traceable to the records also.

Reactor O, the 12-year-old girl, seems to use a method similar to that of D, though it is not so plainly observable either in her performance or in its effect upon the scores. Her words are, "It seems easier to hold with my right foot," and again, "I like to push with my right foot." She shows an excess of only 3.5 per cent on the left.

Both adults report a preference exactly opposite to the method stated above. X and Y mention liking to initiate efforts at balancing from the right side. Reactor Y makes the statement that, although she prefers

to start from the right side, she does make the effort from both sides; also she states that when blindfolded it is easier to shift from right to left than *vice versa*. This preference of method on her part can probably account for her record of a right excess amounting to 6.4 per cent. Reactor X, however, who states his preference just as clearly, averages a negligible difference for the two sides.

Individual analysis of the daily averages for the left and the right side brings out a great variation from day to day in case of all reactors but one. The only reactor exhibiting consistency is D, who has the 16.7-per-cent excess on the left. Her every trial except one out of the 24 shows excess on the left. Examination of the scores for the six work periods in a day's trial does, however, show a slightly greater variation there. Table 5 gives the number of trials showing left-side excess as compared with the number showing right-side excess for each reactor. This comparison is worked out on the basis of trial average scores and also from best-work-period scores.

It might be considered that the most nearly characteristic preference as to sidedness appears in the best single short work periods. In trial scores computed on this basis, D in 24 trials shows left-side excess in only 18 and a total left-side excess of 16.4 per cent, illustrating a negligible difference between sidedness as computed from average and from best-work-period scores. Examination of the means for boys and for girls does bring out a greater equality as to sidedness in the frequency and also a slightly greater equality in

TABLE 5

SIDEDNESS IN EQUILIBRIUM AS SHOWN BY FREQUENCY AND BY PERCENTAGE OF LEFT-SIDE EXCESS

			Basis of trial averages				Basis of best-work-period scores			
			Frequency				Frequency			
Reactor	Sex	Trials	left excess	right excess	Left-right	% total efficiency difference left-right	left excess	right excess	Left-right	% total efficiency difference left-right
D	F	24	25	1	22	.167	18	6	12	.164
H	F	24	9	15	— 6*	—.019	10	14	— 4	—.035
E	F	24	13	11	2	—.006	8	16	— 8	—.050
F	F	24	17	7	10	.089	14	10	4	.061
Mean	F	24	15.5	8.5	7	.058	12.5	11.5	1	.035
G	M	24	17	7	10	.059	15	9	6	.055
C	M	24	17	7	10	.059	13	10†	3	.059
B	M	24	17	7	10	.042	13	10†	3	.068
A	M	24	18	6	12	.052	15	9	6	.005
Mean	M	24	17.2	6.7	10.5	.051	14	9.5	4.5	.047
Mean	M&F	24	16.3	7.6	8.7	.054	13.2	10.5	2.7	.041
Adults										
X	M	24	12	12	0	.003	13	8‡	5	.010
Y	F	24	7	17	10	—.064	6	18	—12	—.064

*Minus sign denotes right-side excess.
†One work period shows same score for left and right.
‡Three work periods show same score for left and right.

the percentage efficiency of the best work scores. However, as to individuals, this is variable, since some show greater sidedness in the average and some in the best-work-period method of scoring.

A study of sidedness of the individual children with reference to the influence exerted by the changes of stimuli introduced in the series is presented in Table 6. These results show extreme variability between individual responses. This is most noticeable again among the girls who have already been reported as subject to the least uniformity in the practice series.

The addition of the white stripe to the board might be expected to decrease sidedness since it indicates the center axis. Foot placement with reference to the line is also guided at that time. Five trials are probably too few in number to constitute a reliable basis for judgment in this test. However, in the five trials introducing the mid-axis stripe, only one girl, D, reduced sidedness, and that only 1.3 per cent. The other three vary about as widely as is possible. H increased right-side excess 5 per cent; F increased left-side excess 2 per cent; E changed from right-side excess to left-side excess, making a total modification of 7.3 per cent. The four boys as usual show considerable uniformity, reducing sidedness in three cases 6.5 per cent, 4.2 per cent, and .8 per cent and increasing it in only one case by a mere .7 per cent. The mean for the 8 children shows a 1.3-per-cent reduction of the amount of sidedness recorded in the previous long practice series.

The use of the arrow supplies a definite visual indication of success in equilibrium. It may perhaps be

TABLE 6
SIDEDNESS IN EQUILIBRIUM AS INFLUENCED BY VARIATIONS IN SERIES
Differences of means (percentage), left minus right

Reactor →	Number trials	D	H	E	F	Means, female (omit H)	Number trials	Adults X	Adults Y
Variations:									
Practice	17	.175	—.011*	—.026	.085	.075	24	.003	—.064
White line	5	.160	—.061	.047	.106	.104			
Arrow + line	10	.145		.007	.061	.071			
Control	5	.080†		—.041‡	.095§				
Blindfold	3						10	.054	—.153
Control	1						1	.145	—.080
Retention	8						3	.112	
Reactor →	Number trials	G	C	B	A	Means, male (omit G)		Means, 6 reactors	
Variations:									
Practice	17	.099	.059	.021	.058	.046		.060	
White line	5	.034	.017	.028	.052	.032		.068	
Arrow + line	10		.001	.206	.021	.076		.073	
Control	5		.023	.015	.070	.036		.036 (3 male)	
Blindfold	3		.040	.034	.062	.044		.044	
Control	1		.077	.124	.025	.075		.075	
Retention	3				—.023				

*Minus sign denotes right-side excess.
†Four trials.
‡Three trials.
§Two trials.

assumed to emphasize visual cues with reference to lateral oscillation and to give training in the use of such cues. In static equilibrium it has been found that the use of visual cues quickly corrects lateral sway (Miles, 118). It is perhaps to be expected therefore that reduction of sidedness might result from this series. This expectation is borne out in the case of all but one child, reductions in sidedness amounting to 1.5 per cent, 4 per cent, 4.5 per cent, 1.6 per cent, and 3.1 per cent. One boy, however, for reasons unaccounted, increased his usual sidedness 17.8 per cent. Without this case, the average on a comparable number of cases throughout shows an indication of a slight reduction—about 2 per cent—for the arrow series. With this case included, the mean shows an increase of sidedness necessarily rather than a decrease.

Sidedness in the five control trials following use of visual cues again shows variable individual increase or decrease. The average of the three boys shows a 4-per-cent decrease in sidedness in the control following the arrow-plus-line series.

The *total reduction in sidedness from the original* long practice series through the white line and the arrow-plus-line series to the control is perhaps significant. Reactor D, beginning with the excessive 17.3-per-cent sidedness, has reduced this to 8 per cent, 6.5 per cent of this reduction taking place in the control series following the use of visual cues. Reactor E has slightly increased her right-side excess, and Reactor F has slightly increased her left-side excess, though both had reduced this excess during the visual training.

One boy has increased his left-side excess 1.2 per cent in the entire time, though the two others show 3.6-per-cent and .6-per-cent reduction. B shows the slight total decrease of .6 per cent in his left-side excess in spite of his phenomenal increase of sidedness during the arrow-plus-line series. Not only that increase was lost but additional reduction was made when the visual stimulus was removed.

The three boys of the children's group who were given a short blindfold series show only a .9-per-cent average increase in sidedness. This blindfold series of three trials is probably too short to be indicative. The two adults in a series of 10 blindfold trials increase a left-side excess in the 24 practice trials by 5.1 per cent and a right-side excess by 8.9 per cent. Whether visual cues play a greater proportional part with adults than with children in prevention of excessive sidedness is an interesting question which can be made clear only by further experimentation. It is of course possible that increase in sidedness of the blindfolded adults is merely a concomitant of the general disturbance in equilibrium occasioned by cutting-off of visual cues and *not significant* of the comparative relationship of any two factors of control.

An analysis of the records of the four reactors who show exceptional changes of any kind in sidedness is interesting, particularly since in each instance there appears to be a relationship—though a differing one—to visual cues. These four, Reactors D, B, X, and Y, were all enthusiastic, interested workers. From the data at hand, D and X appear to be exceptional in body

balance as measured by the balancing-board. B and Y can probably be classed excellent. All were apparently in excellent health and had no defects, visual or otherwise. All four show unusually good physique and are skilful in general motor activities. A case history of each with reference to sidedness is presented. Parallel numerical records using grouping by five's for the closer study are given in Table 7.

TABLE 7
VARIATIONS IN SIDEDNESS THROUGH LEARNING SERIES IN EQUILIBRIUM
Differences (percentage), left minus right

Trials	Series	D Average	D Best	B Average	B Best
1- 2	Practice	.145	.056	.029	.107
3- 7	Practice	.101	.062	—.004*	.014
8-12	Practice	.156	.126	.051	.090
13-17	Practice	.275	.229	.010	—.023
18-22	White line	.165	.196	.028	.053
23-27	Arrow + line	.170	.0296	.239	.291
28-32	Arrow + line	.121	.0840	.171	.057
33-36	Control	.080	—.0824	.012	.053
38-40	Blindfold			.034	

Trials	Series	X Average	X Best	Y Average	Y Best
1- 5	Practice	—.043	—.012	—.069	—.090
6-10	Practice	—.039	—.038	—.127	—.106
11-15	Practice	—.010	—.001	—.060	—.019
16-20	Practice	.022	.054	—.036	—.055
21-24	Practice	.119	.059	—.031	—.044
25-29	Blindfold	.102	.085	—.112	—.199
30-34	Blindfold	.025	.138	—.194	—.235
35	Control	.143	.072	—.080	—.161
36-38	Retention	.113	.186		

*Minus sign denotes right-side excess.

Reactor D, Female, 4 years 9 months, IQ 115

Reactor D holds the highest mean record for the children's group on the basis of 24 trials. Her quite exceptional left-side excess of 17.3 per cent has been previously mentioned. Also her reduction of

this excess to 8 per cent in subsequent trials has been stated. This modification of 9.3 per cent in sidedness as shown in Table 5 is greater than that of any other child except B.[3] It is true the control series of only 4 trials appears from study of the records to be too short to indicate whether this as a more nearly permanent learning or a momentary chance effect. If we follow D's record through from the beginning, however, this last reduction appears to possess some possibility of significance. It will be noted in Table 7 that throughout the practice series D showed a strong tendency to increased sidedness. This was, however, greatly checked by the addition of the white line and the control of foot placement. The second five trials of the arrow series show a still further reduction in sidedness and also improvement in average score. Some basis apparently exists for the conjecture that the control of visual stimulation as attempted in the arrow series may be associated with the reduction in sidedness in that series and perhaps also in the following control series.

The best single work periods show throughout perhaps a slightly greater tendency to uniformity of right and left. However, they show the same general tendency to increase of sidedness during the long practice series. A sharp decrease in difference between left and right is present in the arrow series. The best single records show even a reversal to an 8-per-cent right-side excess in the final control.

By both methods of recording, a change in general tendency appears during the arrow series. The tentative assumption seems therefore justified that in the case of D some control of visual cues may have acted as a cause for reduction of sidedness. Progressive training effect may also have been present.

Reactor B. Male. 4 years 9 months. IQ 113

Reactor B in the children's group holds the rank of fifth as determined by the mean scores of 24 trials. He is, however, less than 1 per cent below the child ranking fourth. As observed, he appears to be one of the most skilful of the children in balancing. He was

[3] E shows the next greatest change with regard to sidedness. Her modifications may perhaps be inferred to be more nearly referable to foot position and influence of the white line, though some relation to visual cues is probably also present.

in general a tireless worker, though a playfulness occasionally exhibited may have lowered his total score.

As shown by the differences presented in Table 7, B exhibited no pronounced sidedness at any time previous to the arrow series. His greatest left-side excess is 5.1 per cent shown in trials 8 to 12. His average sidedness in 22 trials preceding the arrow series is 2.2 per cent, a left-side excess.

Averages for the arrow series, however, reveal a left-side excess of 23.9 per cent in the first 5, reduced to 17.1 per cent in the second 5 of the series with a negligible gain in skill during the 10 trials. The control series of 5 trials following shows an immediate reversion to his former tendency to equalization in a left-side excess of 1.5 per cent. The control series also brings a jump of 4.6 per cent in skill which constitutes an unusually large gain for only 5 trials.

It is possible that B, probably contrary to D, has already built up a reflex mechanism which used visual cues in a rather expert manner. The arrow series may have greatly disturbed this previous efficient pattern of response, as assumed, thus causing marked increase of sidedness. The reduction of sidedness by 6.8 per cent in the second 5 of the arrow series may be interpreted as unusually rapid adaptation to the new pattern of visual cues. It is probably too much to assume that the almost perfect equalization and the marked gain in equilibration of the control are partially a result of training during the arrow series. Assuming a previous unusually efficient use of visual spatial cues, it can at least be stated that the training in the arrow series effected no subsequent detriment to such a pattern. The reactor returned immediately to a much increased efficiency in balancing and to a minimum evidence of sidedness.

Sidedness is again increased during the blindfold series, though it cannot be said that it would not have increased without it.

The trend as set forth in best single records is in general similar to that of the averages though changes frequently show up in a more exaggerated form.

Detailed study of B's records for sidedness can be said to show nothing especially remarkable other than a pronounced modification during the arrow series. This record does not negate a hypothesis that adequate control of visual cues may affect sidedness or that training in the use of visual spatial cues may tend to decrease sidedness.

Reactor X. Male. Age 23 years

Reactor X is a most active young man of seemingly exceptionally quick response. He appeared genuinely interested in seeing how great a skill in balancing he could build up. His willingness and his ability to expend consistently the maximum of effort through a long learning series is unusual. His record of achievement on the balancing-board appears quite exceptional.

Reactor X shows on the 24 practice trials an average sidedness of only .3 per cent, indicating an almost equal use of right and left sides. However, analysis of sidedness from the beginning to the end of the experimental program reveals variations of some apparent significance. As recorded in Table 7, differences of left and right average scores show in the beginning a 4.3-per-cent right-side excess. This right-side excess is reduced by a fairly regular gradation to negligible quantity by the end of 15 trials. At the end of 20 trials it has been reversed to a 2.2-per-cent left-side excess which is increased to a left-side excess of 11.9 per cent by the end of the 24 practice trials.

The marked increase in sidedness on these last 4 trials, together with a marked loss in efficiency in balancing, furnishes some indication that with this reactor reduction in sidedness is partially an accompaniment of gain in ability. His previous regular decrease in sidedness had accompanied a similar regular gain in balancing-skill.

The gradual reversal from a medium right-side excess to a marked left-side excess presents a curious problem. That this is not a simple matter of chance is evidenced by the regular progression and by the change also in frequency of excess as to daily trials from the right to the left side. The first 15 trials show 11 with right-side excess. The next 9 trials show 8 with left-side excess. The same trend from right- to left-side excess is shown by the best single records though in these records a right-side excess is more nearly negligible from the beginning.

Data of the blindfold series appear to supply a clue as to the cause of this progressive change. When all visual cues are removed, the trend is definitely back again toward right and left uniformity. The first five trials of the blindfold series show a 1.7-per-cent reduction in left-side excess in spite of this confusion of the response pattern. The second 5 trials with the blindfolded reactor's strenuous efforts to make a gain under those conditions show a remarkable decrease to

within 2.5 per cent of uniformity right and left. This reduction is *accomplished too by a close equality of right and left in each trial* rather than by a large excess now on one side, now on the other. Trials 30 to 34, the last 5 of the blindfold series, show the following left-right relationship in comparison with trials without blindfold before and after (Table 8).

TABLE 8

Trial	Series	Left	Right	Average
21	Practice (no blindfold)	.285	.145	.215
22	(no blindfold)	.297	.173	.256
23	(no blindfold)	.362	.186	.274
24	(no blindfold)	.294	.257	.275
30	Blindfold	.325	.324	.324
31	Blindfold	.346	.321	.333
32	Blindfold	.347	.348	.348
33	Blindfold	.345	.309	.327
34	Blindfold	.367	.303	.335
35	Control (no blindfold)	.341	.198	.269

The contrast of the equality shown during the blindfold series and the marked sidedness exhibited before and immediately after when visual cues are again permitted is of striking character. It is unfortunate that it was necessary to base the final control upon only the 1 trial instead of upon a series of 5 or 10 trials.

Three trials constituting a retention series, 3½ months later, show still an 11.2-per-cent left-side excess.

The most tenable theory to explain X's history as to sidedness appears to point definitely to his pattern of visual cues. These were uncontrolled for the adults except during the blindfold series. A tentative assumption is perhaps permissible that something in his evolving habit pattern with regard to use of visual cues administered training favoring a left-side excess. This appeared to be gradually overcome when visual cues were cut off, but to be immediately reinstated with removal of the blindfold. This history appears to support a hypothesis as to the influence upon sidedness to be exerted by training in use of visual spatial cues.

Reactor Y, Female, Age 20 years

Reactor Y is unusually skilful in sports and in feats of motor co-ordination. Her proficiency in riding the bicycle is rather remarkable, and she is also an accomplished horsewoman skilled in jumping. Her method of reaction on the balancing-board was not of the rapid-fire activity type shown by X. She showed a slightly slower but well-calculated, careful effort. In attitude toward the test and toward her methods she was highly analytical. Performance throughout was consistently earnest and vigorous in spite of a train of circumstances probably somewhat untoward as far as test achievement is concerned.

Reactor Y's preference as to initiation of effort from the right is in line with that expressed by X. It is exactly opposite to the method used by the two children B and D, who worked with left foot down and right foot up and active.

The results of this opposite preference, however, are much more marked in the case of Y than with X. Y shows the right-side excess throughout, though again, as with X, an approach toward right and left equality is strongly evidenced with increase in proficiency. Trials 16 to 20 and 20 to 24 show a reduction of right-side excess to only 3.6 and 3.1 per cent, respectively. The two adults X and Y reduce sidedness as they increase in proficiency in an uncontrolled practice series. On the other hand, the two children B and D in a series similar but not so long show increase of sidedness with increase of proficiency. Individual differences as to methods of compensation appear to cover a broad range.

However, removal of visual cues in the blindfold series serves markedly to increase Y's sidedness which in the continued confusion of the second 5 trials without gain in proficiency reaches the high mark of 19.4-per-cent right excess. Y's blindfold record of marked increase in sidedness following a previous tendency toward equality shows an effect exactly opposite to that exerted upon X. In his case, the blindfold served to stabilize momentarily an increasing tendency to sidedness.

Following removal of the blindfold, Y returns at once toward her former amount of right-side excess. This is in accord with X's immediate return toward his previously established left excess.

Several conjectures can perhaps be advanced with regard to Y's record as to sidedness. Certainly her preferences of position, her method of work, and her general results in sidedness are exactly

opposite to those of D, for instance. Y, showing a right-side excess, can perhaps be said to be using the compensations connected with the left side of her body more expertly than those connected with the right. Her characteristics of sidedness in equilibrium seemingly correspond to the characteristics of left-handedness though she is not left-handed.

Among the several observable factors which may be supposed to be operative in producing sidedness are weight, strength, skill, and visual spatial reflexes, as well as other more subtle influences. If any of these play an unusually important part in this case to cause the right-side excess, it would seem to be something other than the visual reflexes. Though showing the right-side excess consistently before, with visual cues cut off, evidently some restraining influence is eliminated and a greater dominance of the factor producing the right-side excess occurs. Upon removal of the blindfold, visual cues again cause a quick return from the excessive sidedness. It may be argued that the increase of right-side excess during the blindfold series simply shows general disturbance of the usual pattern and does not indicate anything with regard to the relative influence of different factors. This would hardly seem a valid argument in the case of this practiced, careful reactor. Also, why did it not operate to increase X's marked left-side excess? Why, also, was it not noticeable in the blindfold series of the little boys who might, because so young, be expected to show more of a reaction of disturbance than an adult?

The present data cannot provide a solution to the questions asked. Much further work must be done to solve the problem of the origin of sidedness and of the proportionate influence of the factors operative. Obviously, it is not a simple matter of greater weight, greater strength, or greater skill of the one side. Sidedness appears to be the resultant of the algebraic sum of a number of subtle factors difficult to separate. Some obviously have a counteracting effect and others appear to reinforce each other. Whether or not one factor acts to dominate is also a task for future determination.

The fact that modifications in sidedness do occur is significant. The fact that these occurred gradually, showing progression over a length of time, is also significant.

Study of these four case histories as to sidedness serves to emphasize the part played by visual cues. However, the type of influence exerted by visual spatial habits apparently varies considerably among individuals.

Sidedness is shown in another way not measured in this experiment. The amount of control exerted by the right side is, in general, apparently the greater. Descent governed primarily by the left side of the body appears to be more abrupt and forceful. This is evidenced by observation of the reactor's performance and also by examination of certain details of the records. The records give some indication of a tendency to a certain amount of equalization of the force of descent with continued practice. However, direct evidence of this difference in control by the two sides, since not measured by the apparatus used here, is not amenable to presentation. The addition to the apparatus of a means for recording the relative force of descent on each side is particularly valuable in any study of sidedness.

The results with regard to sidedness in equilibration as measured by the balancing-board may be summarized as follows:

1. A general tendency toward greater efficiency of the right side of the body is shown.

2. Some individuals show greater efficiency of the left side.

3. Variation between individuals as to amount of sidedness is considerable.

4. There is some indication that sidedness decreases with increase in skill in equilibration.

5. In this experiment girls showed considerably greater variation with reference to sidedness than boys.

6. Individual differences as to pattern of method and preference are found.

7. Difference in force of descent on the two sides is probable.

8. Visual spatial coordinations apparently affect sidedness in different ways in different individuals.

9. Sidedness appears to be amenable to training perhaps by use of visual cues.

10. Apparently, newly acquired habits of sidedness in equilibration may persist for three months without specific practice.

D. Control of Foot Position

Tables 9 and 10 show by means and by percentage of gain the effects of the attempt at control of foot position. The average gain for either boys or girls is slightly less in the white-line series than in the corresponding period of practice with no such control. Study of individual scores shows that two boys made a better gain in this segment than in either of the two previous periods. One shows a negligible gain and one even suffered a loss. The girls individually give a much similar variation.

TABLE 9

MEANS FOR PRACTICE AND WHITE-LINE SERIES IN EQUILIBRIUM

Trials→ Series→ Reactor	Sex	3-7 Practice	8-12 Practice	13-17 Practice	18-22 White line
D	F	.377	.368	.361	.361
H	F	.400	.384	.347	.380
E	F	.396	.407	.408	.377
F	F	.422	.373	.396	.375
Mean	F	.399	.383	.378	.374
G	M	.389	.377	.354	.368
C	M	.395	.386	.370	.369
B	M	.394	.379	.385	.369
A	M	.387	.391	.396	.381
Mean	M	.391	.383	.376	.372
Mean	F&M	.395	.383	.377	.375

TABLE 10

PERCENTAGE GAIN OR LOSS IN PRACTICE AND WHITE-LINE SERIES IN TEST OF EQUILIBRIUM

Trials→ Series→ Reactor	Sex	8-12 Practice	13-17 Practice	18-22 White line	8-22 Absolute gain
D	F	.009	.007	.000	.016
H	F	.016	.037	—.033	.020
E	F	—.011	—.001	.031	.019
F	F	.049	—.023	.021	.047
Mean	F	.016	.005	.0047	.0245
G	M	.012	.023	—.014	.021
C	M	.009	.016	.001	.026
B	M	.015	—.006	.016	.025
A	M	—.004	—.005	.015	.006
Mean	M	.008	.007	.0045	.0195
Mean	F&M	.012	.006	.0046	.022

Certainly no significant results can be said to have appeared from this attempt at control. The method used in the attempt does not pretend more than partial control. Presumably the white line strongly but casually directs attention to the fact that there is a center axis. It locates the center axis as well as assisting the child's concept of symmetrical placement. It was desired to accomplish this with a minimum of disturbance or inhibition of the preferred placement. What inhibition existed was probably concerned with the child's desire to comply with the instruction to keep the feet an equal distance from the line in a position which was almost daily pointed out. This desire and the consequent direction of attention toward foot position could be a sufficient distraction to interfere with the performance.

Ideas as to what may constitute adequate control of foot position in young children probably vary. The painted outline of the sole on the board at positions equidistant from the axis and the insistence that all children observe this same distance between the two feet does not appear to give equal advantage to all. Some may prefer a narrower stance, some a wider; while some may be exactly suited by the stance imposed. A study of the preferred distances as used by each child might make it possible to estimate the individual's preferred stance. Wide varicolored stripes placed parallel to the mid-axis and in symmetrical order might be used to assist the child without too much inhibition to take an equidistant position and to maintain the same from trial to trial. Obviously the feet

must be free to make small adjustments. Any interference with the fullest activity either by mechanism or by suggestion disturbs the general pattern and hampers the performance probably to a varying degree in different reactors.

Preference as to width of stance appears to be rather generally developed by the seventeenth trial. Observations as to this point were made throughout the program. The majority of the earlier records showed a wide stance, that is, 10 or maybe 12 inches. With practice this was narrowed rather rapidly to about 4, 6, or 8 inches for the different children. A child who habitually used a narrow stance sometimes began with a wider distance but narrowed this after a work period. The individual child seemed to develop a quite definite feeling as to what constituted his "right" foot position. One boy when asked the routine question used in the control of foot position "Are your feet right?" answered, "I want them just a little bit closer." He, together with the others, frequently worked meticulously to place his feet just where he desired them for the work. This meticulous quality and the feeling for precision in themselves may be considered as symptomatic of a considerable amount of distraction by the attempt at control. However, it is possible, too, that, while attention to this detail is during the time associated with some general loss in achievement, yet some subsequent achievement perhaps may be attributed to an improved method of foot placement now become more nearly automatic.

This last observation calls into question the validity

of the method used to measure the gain or loss presumably to be attributed to any one variation in the stimulus pattern. The measurement of the amount of gain in any one segment of a learning series offers difficulties within itself. The method chosen consists in throwing the series into groups of five for which mean scores are set up. Since all scores in the balancing-board experiment are computed on the basis of 100 per cent, 0 being a perfect score, the difference between the means for the groupings by 5 constitute a gain or loss in percentage on a constant basis of perfection. Certain inadequacies in this method are admitted since a loss in one "5" may be followed by a seemingly more than legitimate gain in the succeeding "5." However, errors of this nature are not obscured but are readily observable. Approximate correction is readily made.

However, the question of the validity of the estimated loss or gain as measuring an increment assignable to influence of foot position or of visual cues alone remains unsettled. In general, it may be assumed that a significant modification in response associated with a series characterized by a modification of the stimulus pattern may indicate potential causal relationship. However, in a complicated activity such as equilibrium there are many counteracting factors. Also, there is no clear evidence that by some mechanism of summation or of maturation with exercise a modification which at the time introduced apparently is associated with loss may not be partially responsible for a gain at some subsequent period.

These two important discrepancies with regard to

the method of analysis of loss and gain in the course of the learning series are recognized. The necessity for certain allowances is frankly admitted. Nevertheless, *for the present purpose*, this simple method is considered more suitable than the more complicated formulae for computing rate of increase in the segments of a learning curve.

The changeable factor of motivation is also to be considered with reference to comparison of gains and losses from group to group within the series. It is doubtless true that certain variations in the series served to increase motivation at the time introduced and so the results are clouded by the variations in motivation. However, to carry through so long a series with the kind of activity tested and using young children appears to be practically impossible without sufficient variation to keep up motivation. Also, a long learning series in which motivation gradually declines is subject to the same or even worse difficulties of interpretation. Every effort was made throughout to keep up a high motivation. That this failed at times is probably indicated by the loss recorded by both adults in trials 21 to 24. It is possible that a part of the general loss recorded by the children for the period of the use of the white line is due to boredom. The detail of the addition of the white line does not appear to have much motivating power. Although it is impossible to estimate relative motivation, yet it is believed to have been fairly regular throughout except perhaps through trials 13 to 22. During this period there may have been a slight decrease, not in any way noticeable with all children.

Motivation differs between the children also. F and C show the least motivation throughout, seemingly due to the infrequency of successes and the effort necessary for achievement. On the whole, however, they were cheerful and worked with pleasure. A, although he told his mother he didn't think he was very good at balancing, was always most cheerful and persistent. E, in spite of quite evident disappointment at times because of inability to hold, worked with energy and exceptional persistence. Her gratification when she at last began to have some feelings of success seemed effective in spurring her to still greater effort. D, who holds the best record throughout, can be said also to have shown the best and most consistent motivation as compared with the other children. A slightly easier test of equilibrium in which all children can sense achievement will probably more nearly equalize motivation both as between reactors and as between the progressive series.

E. Control of Visual Cues—Arrow Series

The data of Tables 11 and 12 present the results of the arrow series. Mean gains of the six children who completed the series are shown to be slightly higher in the two groupings of this series than in any grouping of a preceding series. The absolute percentage gain for trials 23 to 34 is 3.1 as against 2.2 per cent for trials 8 to 22. The boys' absolute gain exceeded the girls' by 1.4 per cent in the arrow and control series while the girls' absolute gain exceeded that of the boys' by .5 per cent in the practice and white-line series. It

TABLE 11

MEANS FOR WHITE-LINE AND ARROW SERIES IN TEST OF EQUILIBRIUM

Trials→ Series→ Reactor	Sex	18-22 White line	23-27 Arrow	28-32 Arrow	33-34 Control
D	F	.361	.345	.335	.329
E	F	.377	.354	.333	.335
F	F	.375	.398	.403	.376
Mean	F	.371	.364	.357	.347
C	M	.369	.332	.347	.353
B	M	.369	.364	.366	.320
A	M	.381	.369	.332	.331
Mean	M	.373	.355	.348	.335
Mean	F&M	.372	.359	.352	.341

TABLE 12

PERCENTAGE GAIN OR LOSS IN WHITE-LINE AND ARROW SERIES IN TEST OF EQUILIBRIUM

Trials→ Series→ Reactor	Sex	23-27 Arrow	28-32 Arrow	23-32 Total arrow gain	33-34 Control	23-34 Absolute gain
D	F	.016	.010	.026	.005	.031
E	F	.023	.021	.044	—.002	.042
F	F	—.018	—.010	—.028	.027	—.001
Mean	F	.007	.007	.014	.010	.024
C	M	.037	—.015	.022	—.006	.016
B	M	.005	—.002	.003	.046	.049
A	M	.012	.037	.049	.001	.050
Mean	M	.018	.007	.025	.014	.038
Mean	F&M	.013	.007	.019	.011	.031

may be possible that the boys show significant superiority in skill in the arrow series. Superiority in this arrow series may be construed to indicate superiority

in educability of visual reflexes or superiority in ability to resist disturbance of the usual pattern or, again, superiority in some other unidentified factor. The boys, A and B, made gains of 5 per cent and 4.9 per cent, respectively, in trials 23 to 34 as against the girls' highest gains of 4.2 per cent and 3.2 per cent as scored by B and D. F, a girl, the poorest in general score throughout the entire test, registered even the negligible loss of .1 per cent in this same time. Four children of the six completing the arrow series made in this series their greatest gain for any group of 5 trials. This highest gain as registered by each of these four reactors was approximately twice the next highest gain registered by that reactor. As judged in the small number of cases, there appears to be some evidence for an increased rate of improvement during the arrow series.

An increase in learning during control of visual cues is in accord with the educability of visual reflexes in manual localization. Maxwell (101), as well as Magnus and de Kleijn (96, 97), has demonstrated the direct relationship of the compensatory reflexes of the eyes to bodily orientation in space. It is possible, however, that the learning series here should include 15 or 20 rather than only 10 trials. Also, there are defects in the experimental program itself and in the device of the moving arrow with reference to showing forth clearly the effects of visual cues. It is believed that for this purpose all moving and fixed parts of the apparatus except the balancing-board itself should be screened with a mat surface of a homogeneous char-

acter such as to eliminate spatial cues in so far as possible. A training period with the child facing a large smooth flat screen might seem to constitute some approach to a zero condition. For visual cues the use of four fixed colored rods set in diamond formation with two opposite points exactly in line with the mid-axis of the board seems to have advantages over the moving arrow. Their distance from the child, the continued use of the homogeneous background, and adequate control also appear important. In such a set-up a device for fixation and for a control by increase of small eye movements are also possible additions which have bearing upon the same part of the problem.

F. Blindfold Series

The results from the blindfold series afford some additional information as to the rôle of the visual spatial coordinations. Tables 13, 14, 15, 16, and 17 give the data for the three boys of the youngest group

TABLE 13

Means and Percentage Loss and Gain for Blindfold and Control Series in Equilibrium (Children)

	Trials→ Series→		33-37 Control	38-40 Blindfold		41 Control		% gain blindfold over poorest average of 5	% loss blindfold from best average of 5
Reactor	Sex	Age			% loss		% gain		
A	M	5:0	.332	.353	—.021	.355	—.002	.043	—.021
B	M	4:5	.326	.359	—.033	.350	.009	.035	—.033
C	M	4:10	.345	.382	—.037	.364	.018	.013	—.050
Mean	M	4:9	.334	.365	—.030	.356	.008	.030	—.035

TABLE 14

MEANS FOR PRACTICE SERIES IN EQUILIBRIUM (ADULTS)

Reactor	Trials→ Sex	Age	1-5	6-10	11-15	16-20	21-24
X	M	23	.315	.260	.258	.235	.250
Y	F	20	.344	.335	.302	.288	.299
Mean		Adult	.329	.297	.280	.261	.274

TABLE 15

PERCENTAGE GAIN OR LOSS IN PRACTICE SERIES IN EQUILIBRIUM (ADULTS)

Trials → Reactor	Sex	Age	6-10	11-15	16-20	21-24	6-24 Absolute gain
X	M	23	.057	.002	.023	—.015	.067
Y	F	20	.009	.033	.014	—.011	.045
Mean		Adult	.033	.017	.019	—.013	.056

TABLE 16

MEANS FOR BLINDFOLD AND CONTROL SERIES IN EQUILIBRIUM (ADULTS)

Trials → Series → Reactor	Sex	Age	21-24 Practice	25-29 Blindfold	30-34 Blindfold	35 Control
X	M	23	.250	.338	.333	.269
Y	F	20	.299	.358	.359	.241
Mean		Adult	.274	.348	.346	.255

TABLE 17

PERCENTAGE GAIN OR LOSS IN BLINDFOLD AND CONTROL SERIES IN EQUILIBRIUM (ADULTS)

Trials → Series → Reactor	Sex	Age	25-29 Blindfold	30-34 Blindfold	35 Control	% loss blind-fold from poorest average of 5	% loss blind-fold from best average of 5
X	M	23	—.088	.005	.064	—.023	—.103
Y	F	20	—.059	—.001	.118	—.014	—.070
Mean		Adult	—.074	.003	.091	—.018	—.087

and for the two adults. The expected loss appears in a quite uniform manner with the children, showing an average loss of 3 per cent for the three blindfold trials as compared with a previous control series. The children's slow gain upon removal of the blindfold is notable, though the very slight loss by A at that time is probably only an interesting chance occurrence. The average score during the blindfold series is seen to be somewhat better than the poorest average of 5 trials as made by any of these children. Also the same comparison with the best average from a 5-grouping shows the blindfold average considerably below the best. The difference from the poorest records varies from child to child as portrayed in Figure 4. It might

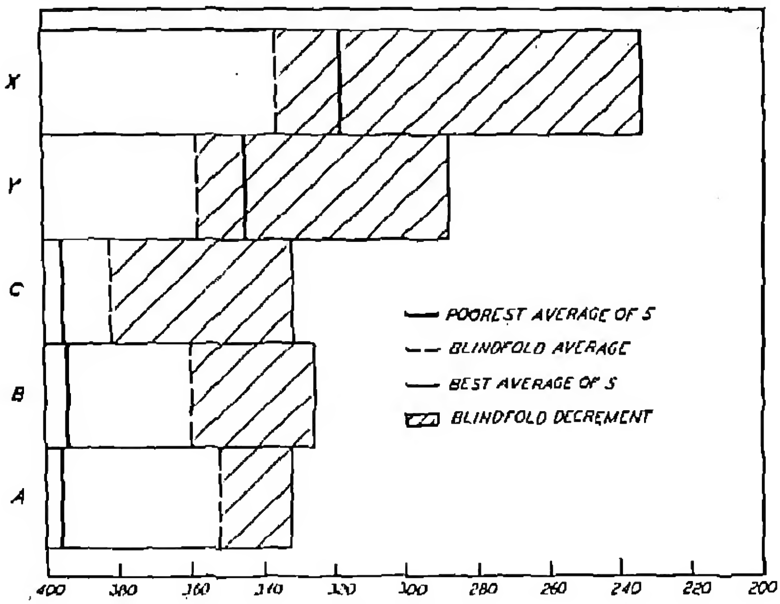


FIGURE 4

GRAPH SHOWING COMPARATIVE BLINDFOLD DECREMENT IN EQUILIBRIUM OF ADULTS X AND Y AND CHILDREN A, B, AND C

appear that C, the child who shows the least difference between blindfold and poorest, uses visual cues to best advantage and places more emphasis perhaps upon that factor than upon proprioceptive or vestibular stimuli. This conjecture receives further support from the fact that this same reactor, C, made a good gain during the arrow series. On the other hand, A, who made the greatest gain—4.9 per cent—in the arrow series, shows the greatest difference between his blindfold records and his poorest average of 5. It might therefore be inferred that A's means of gain in this learning program have been through his eye reflexes but also even more through other mechanisms. B shows about an even division between the effect of vision and of other influences in this learning program.

The loss in efficiency as experienced by the adults in the blindfold series is even more marked than that of the children. In fact, the performance on the balancing-board as shown by the blindfolded adult is only moderately better than that of the blindfolded 5-year-old child. Averages of the three children against averages of the two adults show an adult superiority of only 1.7 per cent when blindfolded. Also, the blindfold record of both adults is poorer than their poorest average of 5 as shown graphically in Figure 4. Both adults show what can undoubtedly be called a large difference between their best grouped average and their blindfold averages. Can it be inferred from these comparisons that practically all of the relatively larger gain by adults in this learning program in equilibration is due to the modifications having to do with

eye reflexes? On the other hand, do the data of the three boys of mean age 4 years 9 months indicate that, while learning capacity in equilibration is due to educability of visual spatial coordinations, yet at that age other factors exert practically equal influence?

That the proprioceptive responses having to do with equilibrium are capable of training in the adult is demonstrated by the achievements in reeducation of Franz (38), Maloney (98), and others. Reactor X shows a very slight perhaps negligible tendency to gain in efficiency in the second 5 of the blindfold series. Maloney, in his work with blind tabetics, attributes dominance in bodily integration of movement to visual sensations and sensations of eye movement. Franz, while admitting the importance of visual and visuo-motor sensations for bringing about certain important finer coordinations, does not concede them the degree of preeminence ascribed by Maloney. Franz states, however, that the professional dancer and the acrobat can frequently continue their occupations for a long period after the beginning of *tabes dorsalis*. This fact would seem to emphasize the extraordinary compensatory power of eye reflexes since in *tabes* the proprioceptive responses of the lower limbs are frequently much impaired. The present data, in so far as adults are concerned, tend to support the theory of a general dominance in equilibration by the visual and visuo-motor coordinations.

Visual and visuo-motor dominance in the integrative pattern of equilibration is not, however, so clearly apparent in children at the age tested. Exploration of

the implications here with reference to maturation brings out several interesting facts. Scammon (47) finds that, judged by size and weight, the nervous system and its related structures exhibit an "initial phase of rapid growth followed by a slower terminal one, although the duration of these two periods may be very different. . . . In all instances these structures have attained above two-thirds of their adult size by the close of early childhood. . . . This type of growth is characteristic of the brain as a whole, of all its various parts and the membranes covering it, of the spinal cord, of the eye as a whole and its several parts, of the several parts of the auditory mechanism and, in all probability, of the ocular muscles." Scammon's curve of neural growth shows approximately 20 per cent of the increment occurring between the ages of 4½ years and 20 years. That the compensatory eye reflexes of children of this age are subject to a certain amount of training with reference to eye and hand coordination is evident from data of these same reactors in a controlled aiming test[4] used in another experiment (12). Comparative data of the rate and the final efficiency of learning of adults in the aiming test, since not related to the purpose for which that test was used, have not been secured. Such data appear to have importance, however, for the present discussion as to comparative educability of eye reflexes of children and of adults. It is possible that the greater

[4]Complete data of the controlled aiming test are filed as a part of the author's Ph.D. dissertation in the library of The Johns Hopkins University.

immaturity of the visual and the eye-muscle reflex mechanisms in the child causes these to assume a smaller proportional part of the responsibility for integration of body movement in equilibrium. The apparent dominance of visuo-motor reflexes over the other reciprocal influences governing equilibrium in the adult may represent a proportional influence present only in the mature structures. In this connection investigation as to the relationship existing between the contributing influences in the equilibration of the 8-year-old child may hold special interest. The 8-year-old boy, it will be remembered, gave evidence of an unusual gain in skill apparently associated with his age level. Although much additional work must be done for any conclusive results, data at hand from the balancing-board point to significant indications regarding differential maturation of structural mechanisms influencing equilibration.

G. Eye Fixation

In discussion of the control of visual cues, mention should be made of eye fixation. Although common experience shows an increase in steadiness with fixation, no attempt at such control was made in this program. Obvious difficulties arise as to the adequacy of a method of control suitable for use with children. Most of the reactors did build up more or less of a habit of watching some particular point. They usually looked down at some moving part of the apparatus which had a relation to the mid-axis. One difficulty in the use of the arrow series existed in the child's con-

flict between previous tendency to look down and his desire to comply with the new requirement. The moving arrow evidently had some interest value to the child. However, that the habits of eye direction already formed had some real hold upon the children is probably shown by their remarks upon removal of the arrow at the end of the series. Several statements such as "I like it better this way," and "It's easier this way" were volunteered.

One child, D, the girl holding the best record of the children's group, may perhaps have formed a habit of fixation which was used frequently. Her face during work periods consistently took on a set sort of "unseeing" expression. This same appearance is noted time after time on her records. It may be interpreted to denote—if anything—any one or a combination of several conditions, namely, eye fixation, concentration of attention, or an "inward" attention to kinaesthetic cues. It is believed that this reactor, unknowingly, of course, quite frequently employed fixation to the advantage of her score.

It now appears of advantage to screen all the moving parts of the apparatus which serve as visual cues and also which disintegrate fixation. A small point of colored light could be arranged in connection with the nearest of the colored rods suggested for controlling visual cues or on a fused background without the rods. A definite perhaps revolving means of disturbance of fixation could also be devised which seems to have possibilities of possessing approximately the same value with regard to concentration of attention.

The height of any device for fixation or indeed for control of visual cues is shown to be highly important. An effort can be made to find a point sufficiently high to obviate any tendency to bend forward and yet low enough to place the edge of the balancing-board within peripheral vision. This lowering of the fixation point is probably advantageous even with the screening of the movable parts, though the devices used should leave the chin free and the neck straight.

Data with regard to control of visual cues during performance on the balancing-board may be summarized as follows:

Arrow Series

1. The arrow series as a means of control of visual cues is accompanied by some tendency to increased rate of improvement.

2. Boys show greater improvement than girls in the arrow series.

3. No evidence is present to negate reference of increased gain during arrow series to educability of eye reflexes.

Blindfold Series

1. Blindfolded reactors, both children and adults, show marked loss of efficiency in equilibration.

2. Blindfolded boys of mean age 4 years 9 months suffer smaller proportionate loss of efficiency than blindfolded adults.

3. When blindfolded, young boys retain part of the increment made in recent learning series; blindfolded adults lose all this increment and suffer even further loss.

4. When blindfolded, adults show negligible superiority to young boys blindfolded.

5. As judged by difference of blindfold average from poorest former averages, young boys show variation in amount of decrement by blindfold.

6. Data indicate greater proportionate emphasis, during learning, upon visual spatial coordinations by adults than by boys of mean age 4 years 9 months.

7. Present data show no inconsistency with facts as thus far gleaned, of differential maturation, or of educability of structures concerned in reciprocal influences governing equilibrium.

8. Data emphasize need for evidence regarding control of eye fixation.

H. Retention of Skill in Equilibrium

Data of the short retention series given after an interval of 3½ months with no specific or similar practice are presented in Table 18. The observation of Hicks (57) with regard to structural maturation is also applicable on the subject of retention. The reactors had no practice on the balancing-board or in any complex skill resembling this during the time elapsed. However, the countless body movements of everyday life incessantly call into play all of the structures and mechanisms operative in the balancing-board test. Continued practice in all the elemental and even the more complex activities of static and progressive equilibrium is recognized, even though the exact combination is not that required for proficiency on the balancing-board.

TABLE 18

RETENTION OF SKILL IN EQUILIBRIUM AFTER THREE AND ONE-HALF MONTHS

Reactor	Age	Trials	Retention av.	Best practice av.*	Difference, retention minus practice	Poorest practice av.*	Difference, retention minus practice
X	23	36-38	.254	.235	—.001	.317	.082
A	5:0	42-44	.312	.332	—.020	.396	.064
O†	11:10	19-21	.278	.266	.012	.337	.071

*Grouping by fives.
†Not comparable in number trials in practice grouping.
Had changed to Cuban heels two months previous.

Reactors X and A are both seen to have exceeded their best grouped average in the practice series. The adult gain is a negligible .1 per cent. The 5-year-old, however, has gained 2 per cent in efficiency which again brings up the question of maturation. The poorest of A's three retention trials is equalled or exceeded only twice in his whole practice series, on trials 37 and 39. He reverses a 5-per-cent left-side excess to a 2-per-cent right-side excess.

Reactor X, the adult, shows the interesting phenomenon of almost 100-per-cent retention. The poorest of his three retention trials was exceeded first in trial 14 of his practice series, again in trial 18 and thereafter in only 4 trials. His best retention trial was equalled or exceeded only three times in his 35 trials of practice, blindfold, and control. He retained the marked left-side excess seen in the latter part of the former series.

The retention score of Reactor O, the 12-year-old girl, shows a loss of 1.2 per cent, though the averages of her practice scores were of necessity irregular and thus not comparable to the regular grouping by 5's of the other reactors. She states quite enthusiastically that it seems easier and reiterates this. She shows a reversal to a right-side excess which may be momentary, existing only in the short series. In addition, on her twelfth birthday, several weeks following her last practice trial and approximately two months before the retention series, she had cast aside her flat tennis slippers and had begun wearing Cuban heels. Her loss of efficiency may be due to the disturbance thus

occasioned in the anterior-posterior position of the center of gravity and thus in her postural reflexes.

Results of the retention series given after an interval of 3½ months without practice are summarized as follows:

1. A 23-year-old man retained newly acquired skill in equilibrium after 3½ months to the extent of approximately 100 per cent.

2. A 5-year-old boy not only retained his former skill *in toto,* but within the 3 retention trials registered an increment of 2 per cent as compared with former best efforts.

3. A 12-year-old girl showed a loss of 1.2 per cent in retention. Change to Cuban heels during the interval clouds the issue.

4. The 12-year-old girl reversed sidedness to right excess in retention, but data are insufficient to determine whether momentary or significant.

I. Control of Attention

Variations in attention, even though slight or most transitory, appear to have an immediate and highly disastrous effect upon performance on the balancing-board. No control of this factor was attempted. Obviously, however, the observation of the moving arrow exerted some control upon attention though introduced for other purposes. The effects of this are not separable in the records.

On the basis of subjective judgment the following statements as to the concentration of attention by the reactors in this experiment can be made. The two

adult reactors and N and O appeared to give excellent attention throughout with relatively little deviation. M was somewhat distractible and talkative. D, as previously mentioned, the best reactor of the group of young children, appeared definitely to give a quality of attention considerably superior to any other member of that group. B and also G are considered to have lowered their records somewhat by a type of distractibility which showed itself in an occasional tendency toward playfulness. G was also inclined to be talkative. I, whose record is next to the lowest in the group shown in the table giving age differentiation, is ranked by observers on the playground as probably superior to all the other children in body equilibrium and feats of agility. Her relative disintegration with regard to attention is believed to account for her low rank in the test of equilibrium.

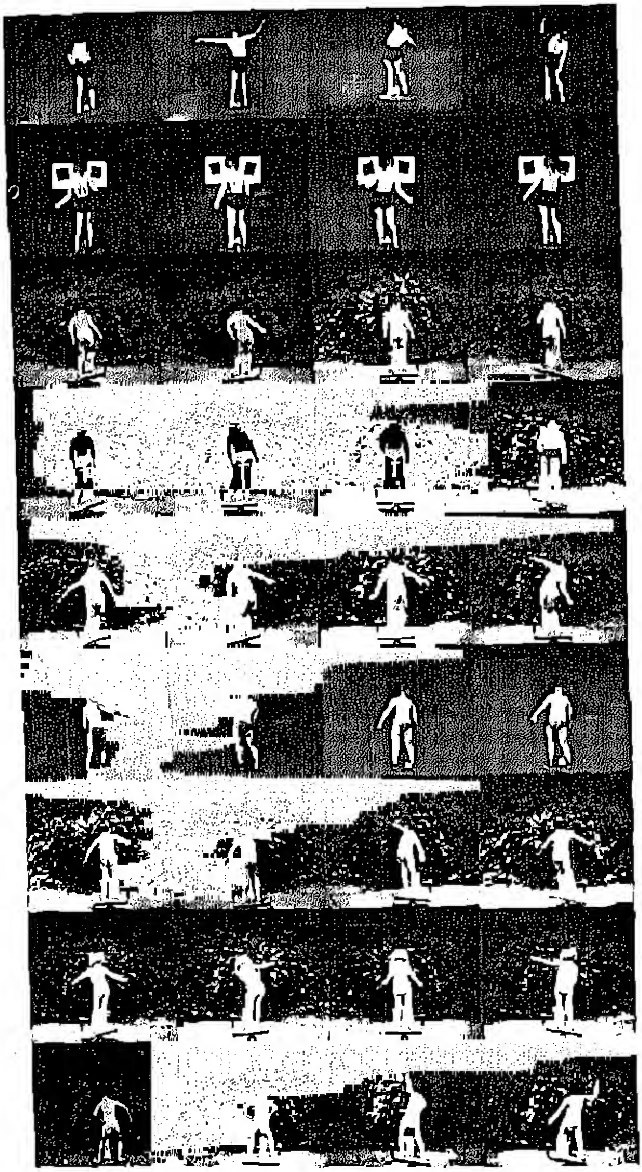
The above observations reveal a need for development of suitable methods for control of attention. For the most dependable results a sound-proof room is probably desirable. Sound is believed to have a generally disintegrating effect upon this activity. The roar of a truck on the road, the chirp of a cricket, thunder, rain, the chiming of the clock in the tower, all are sufficient to cause fluctuation of attention and consequent simultaneous loss of equilibrium. From the present experimentation, attempts at control of attention by visual, perhaps lighting, effects are considered to involve fewer conflicting factors. The complication of a method of this kind by influences of eye fixation and eye movement is to be kept in mind.

Fearing's (34) use of sound distraction with consequent improvement in static equilibrium is highly interesting. For the balancing-board test, the use of sound for distraction may have some value. Some slightly diffuse visual pattern such as the tin cat used by Brown[5] for a different purpose appears to have interesting possibilities especially because of the importance of visual reflexes in equilibration. The lighting-up of the two eyes prevents complication by results of fixation. The cat is in itself interesting to children. The task of watching for and perhaps counting the occurrence of the lighting-up of the cat's eyes as arranged at 2 or 3 irregular intervals in the 30-second work period would appear to offer a practical means of distraction to children of 4 or 5 years.

J. Qualitative Differences in Pattern of Reaction

Individual children, and adults also, exhibit marked qualitative differences in reaction pattern during activity on the balancing-board. These differences in characteristic movements and in variety of movements employed were recorded daily on the record as observed. They are presented in picture form in Plate I, since the pictorial representation brings out the differences in a much more realistic manner than is possible by mere words. The pictures are enlargements made from study of a short moving-picture film taken of each child as well as of the two adult reactors.

[5]Brown, M. W. Device described in *Child Development*, 1930, 1, 266.



D
H
G
C
B
A
E
F
I

PLATE I

Y

X

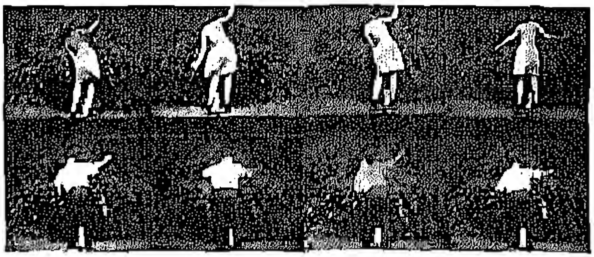


PLATE I (*continued*)

The method of selection was uniform throughout and based on effort to show characteristic poses, as wide a variety of poses as possible and poses related to different positions of the balancing-board with regard to left, right, and center. The group presented of each reactor is believed to constitute a fair representation of the activity of that individual except in the case of the boy G. Reactor G apparently experienced such great pleasure at the thought of having his "picture taken" that he became highly self-conscious. These emotional concomitants served somewhat to inhibit his freedom and amount of activity on the balancing-board.

In order not to affect the learning series, the pictures were taken at the completion of the program by each child. They show the pattern as developed after a considerable length of practice, at least 24 trials for every child but Reactor I, who had been available for only 22 trials. Throughout the learning series there is noticeable a progressive change in the pattern with an increasing smoothing-out of the early extreme, erratic, and extraneous movements as control is developed. These pictures are therefore to be considered

as representing a somewhat advanced mode of reaction which has gone through a relatively great number of modifications and refinements.

The pictures are arranged in rank order on the basis of the 24 trial averages, the best reactor at the top.

Reactor D, at the head of the list, exhibits the freedom and variety of integrated controlled movement characteristic of the star performer. Her free arm swing, use of either arm, now forward, now back, now high, now low, and the extreme plasticity of her whole body movements are all characteristic. This wide variety of uninhibited movements was present from the beginning and seemed to increase as her great activity brought out new useful combinations. Wide fanning movements of the arms were noted from the beginning and toward the end of the series the right whole arm or forearm frequently made complete circumferences. She, X, also a star performer, Y, and H were the only reactors who developed the complete circling, sometimes rapid, sometimes slow, of the right arm or a segment of it. D, Y, and X used it more frequently, more effectively, and in a greater variety of combinations. H used it only with the whole arm and that just before the last.

Reactor X, the man, showed free and varied movement of arms and body from the first. It was because of this spontaneity and smooth control that at the beginning of their white-line series each child was given the opportunity to watch this skilled reactor for ½ minute. This privilege also probably had motivation value, for the children were very fond of him and

liked to play a game in which this man was interested. Some of the children did, without instruction, afterward take on some greater variety of movement. B got the definite idea from seeing X that "waving the arms" was part of the game. He started in enthusiastically to wave his arms whether or not the movement bore relation to his adjustment on the balancing-board. Early results were amusing, but the increase in arm movement rather quickly found relationship to body balance and became a part of his general pattern. C, after seeing X, seemed to try definitely to use more arm and body movement. However, he soon lost this tendency and came back to his previous characteristics, showing a minimum of arm and body movement.

G, for a reactor who attacked the task with boisterous and vigorous method, showed a surprising lack of variety in movement. One especially peculiar development became characteristic. His arms were held stiff at the elbow much of the time. This was particularly noticeable in the left and was accompanied by fingers held close together and stiff like a paddle. This stiff paddle then seemed to act something like a rudder. With the little-finger edge always toward the body, it was moved jerkily to right and left in front of him or backward and forward beside him while the right arm assisted in an almost horizontal position. His progress in learning was characterized by seeming dependence on certain "systems" operative for 4 or 5 trials perhaps. These usually were more concerned with combinations of movement of foot, ankle, and knee. One favorite was from a position down at left to make a quick jump

up to equilibrium and attempt to hold it. This was frequently successful, but finally faded out.

H shows movement in general similar to that of D, though she is considerably less active and more inhibited as to both body and arm movement. She developed a peculiar habit of lifting the right toe from the board and standing on the right heel when balanced. Her left foot was more active than her right.

A was always careful and conservative in his movements.

E and F both, even at this late stage in practice, show severe body contractions though with a considerable variety of movement. The extreme effort noticeable in their pictures is much different from the smooth poise and control evidenced with D. E shows tension in widespread fingers; F shows it in tight clenched fists. By this stage, most of the children while using their hands freely have lost the extraneous movements of clutching and grimacing. These two poorer reactors still show it in marked degree, F particularly using extreme contractions in a wide variety of combinations.

I is the only child who consistently preferred the wide stance with knees bent forward and slightly abducted and arms akimbo on hips. Her movements are free and unrestrained but considerably less in variety than those of D. They have throughout a ludicrous clownish appearance, much different from the smoothness, beauty, and grace exhibited by D and to some extent by H. Although I's movements are jerky, quick, and highly erratic, they give the appear-

ance of relation to body balance. The observer is in the position of always expecting her to make an extraordinary success which she never makes.

Most of the reactors show a habitual slight bending-forward at the hips. This is believed to be more marked with Y and with O. (Pictures of O are not shown.) Pronounced forward bending of the head is noticeable with several children and also with Y. It is believed to be associated with disadvantageous contractions rather than with freedom and control. The pronounced forward bending of the head with Y is probably due in great part to her use of certain visual cues from the moving parts over the axis. It may, however, be due partially to the wearing of high heels. Her movements other than of the head were free, varied, and unusually smooth and well controlled. D is the only reactor, either child or adult, who shows freedom of head movement.

From study of the qualitative differences in body movement, as observed in these reactors, it is believed that increased activity tends perhaps to bring out a greater variety of combinations and so to tend toward greater skill in a way not solely related to speed of reaction. As is to be expected, extreme contractions accompany less skilful performance. Smooth movements apparently associated with less effort accompany control in equilibrium. Distal contractions and other extraneous movements are more noticeable in the less skilled performance.

K. Reliability

Since the small amount of data and the variations in the series render a reliability coefficient of questionable value, such a calculation is omitted. Table 19

TABLE 19

RANK ORDER IN SUCCESSIVE GROUPING OF SERIES

Rank order → Trials	Series	1	2	3	4	5	6	7	8
1-2	Practice	H .364	E .381	A .391	D .395	B .410	G .427	F .431	C .444
3-7	Practice	D .377	A .387	G .389	B .394	C .395	E .396	H .400	F .422
8-12	Practice	D .368	F .373	G .377	B .379	H .384	C .386	A .391	E .407
13-17	Practice	H .347	G .354	D .361	C .370	B .385	A .396	F .396	E .408
18-22	White line	D .361	G .368	B .369	C .369	F .375	E .377	H .380	A .381
23-27	Arrow + line	C .332	D .345	E .354	B .364	A .369	F .393		
28-32	Arrow + line	A .332	E .333	D .335	C .347	B .366	F .403		
33-37	Control	B .326	A .332	C .345					
38-40	Blindfold	A .353	B .369	C .382					
41	Control	B .350	A .355	C .364					

TABLE 20

RANK ORDER IN SUCCESSIVE VARIATIONS OF SERIES

Rank order → Trials	Series	1	2	3	4	5	6	7	8
1-17	Practice	D .372	H .375	G .380	B .390	C .391	A .392	E .401	F .406
18-22	White line	D .361	G .368	B .369	C .369	E .377	F .378	H .380	A .381
23-32	Arrow + line	D .340	E .344	C .346	A .351	G .359	H .362	B .365	F .386
33-37	Control	B .326	E* .331	D* .332	A .332	C .346	F* .383		
38-40	Blindfold	A .353	B .359	C .382					
41	Control	B .350	A .355	C .364					

*D, 4 trials; E, 3 trials; F, 2 trials.

shows the rank order of the reactors in successive segments of the learning series. Though there are considerable variations, it is true, yet D is seen to hold to or near the top throughout. B and C vary around the center. A, F, and E for the most part take the lower places. Much the same general uniformity of relationship is exhibited in the rank order of the variations in the series, as presented in Table 20.

L. Relationship of Equilibration Scores to Other Data

Obviously, the inclusion of correlation coefficients on so small a number of cases is entirely purposeless. Table 21 gives the rank order of the eight reactors of the children's group in equilibrium, nutrition, intelligence, and age. If any relationship exists between the performance on the balancing-board and either IQ or chronological age within this close range, it is not evident from the present data. The relationship of chronological age and ability in equilibrium is suggested by the data of Table 3, covering a wider range of ages. In the same way, it is possible that tests of subjects showing a wide differentiation in intelligence might bring out a relationship there.

However, even on the very narrow range of nutritional status, where every child is considered to be well nourished, there is some indication of a perhaps slight relation between the quality of neuromuscular learning as tested by the balancing-board and nutrition. This suggestion is in line with the previous

TABLE 21
RANK ORDERS IN EQUILIBRIUM, NUTRITION, STANFORD-BINET, AND AGE

Rank order		1	2	3	4	5	6	7	8
Equilibrium 24 trials	Reactor	D	H	G	C	B	A	E	F
	Score	.368	.375	.376	.382	.383	.390	.392	.399
Nutrition rating		D	G	B	E	H	C	F	A
IQ	Reactor	A	G	H	D	B	F	E	C
	IQ	145	121	116	115	113	110	105	87
Age	Reactor	A	C	D	E	B	H	G	F
	Age	5:0	4:10	4:9	4:9	4:5	4:5	4:5	4:4

hypothesis regarding the reactivity of muscle cells exhibiting the optimum chemical balance.

One of the chief difficulties in any study which includes a relationship with nutrition lies in the lack of practical objective methods for measuring nutritional status. The nutritional rating used here is the product of the composite judgments of an experienced pediatrist and the experimenter. The ratings were made at a date quite early in the experimental series and are not believed to be influenced by knowledge of its results since no indications were in evidence at that time. No records had been planimetered. Both pediatrist and experimenter had approximately two years' acquaintance with all but two of the children. The physician had carried the responsibility for their medical supervision during this time and had conducted a complete physical examination of each child as well as observing them under a variety of conditions. The experimenter had weighed and measured all but two of the reactors in two successive years and had been closely associated with them. The nutritional rating is believed to be based upon careful and prolonged impersonal observation. At the same time, it cannot be said to represent a truly objective quantitative measurement.

Animal experimentation at this time places nutritional differences on a basis of biochemical ratios. However of necessity the methods of chemical analysis of blood and of tissue suitable in animal experimentation are not adapted to use in human research. Other techniques of measurement, accurate and objective but

practical for human experimentation, are greatly needed. Dr. Max[9] has developed an induction-coil apparatus which gives promise of filling this need. Such a device, capable of measuring in fine quantitative gradation the threshold of stimulability of certain muscle groups, offers some possibility of providing an advantageous approach to a seemingly impenetrable problem. Conclusive results in this field must wait upon the perfection of some similar means of exact quantitative measurement of neuromuscular efficiency.

[9] Max, L. Laboratory development in 1928, not published.

V

SUMMARY

This present investigation may be said to have raised questions rather than to have settled them. Its purpose has been largely exploratory in a field where with young children only meager work has previously been attempted. Though previously emphasized, it is reiterated here that these results from a limited number of reactors are presented as tentative and indicative, not as conclusive in any way. Any ultimate importance rests upon confirmation necessitating a great amount of further investigation.

A study has been made of motor learning in body balance in relation to nutrition. For this purpose a balancing-board has been used. An extended learning program with specific stimulus variations has been carried on using ten children of mean age 4 years 8 months. Five older reactors of different ages were given the series for purposes of comparison.

From the data of the balancing-board test the following indications of perhaps significant relationships appear:

1. Between the ages of 4 years 8 months and 23 years a slow, slightly irregular increase of skill in equilibrium, with perhaps a more rapid rise from 6 to 8 years, is indicated. In 24 trials adults made a greater percentage gain than children of mean age 4 years 8 months.

2. No sex differences were shown among the chil-

dren other than some evidence of greater variability among the girls and a slight tendency to greater gain by the boys with control of visual cues. Adult differences favoring the male were inconclusive.

3. Sidedness is indicated in a greater but variable efficiency of the right side of the body with cases of slight or marked individual reversal. The girls showed greater variation in sidedness than the boys though both showed individual differences as to method and preference in response pattern. Amount of sidedness may show inverse relationship to skill in equilibration. A probable difference in fine control of descent on the two sides appears. Wide individual differences as to both amount and kind of effect of visual-spatial coordinations upon sidedness are evidenced. Sidedness may be found amenable to change through visual reflexes. Adult habits of sidedness in equilibration, apparently new, may persist for three months without specific practice.

4. Freedom of foot movement, use of individually preferred stance, and position equidistant from midaxis appear desirable. Method of control of foot position in this study was somewhat inadequate.

5. Equalization of motivation indicates need for a slightly easier balancing-device, especially for young children.

6. Attempt at control of visual cues is accompanied by tendency to increased rate of improvement, though a moving device for such control has defects. The boys showed greater gain than the girls during the arrow series. Such gain may perhaps be referable to modifiability of visual spatial reflexes.

Although both showed marked loss, the blindfolded boys of mean age 4:9 suffered smaller proportionate loss of efficiency than the blindfolded adults. Blindfolded boys retained part of the increment gained in a recent learning series; blindfolded adults lost all this increment and suffered even further loss.

Blindfolded boys equalled the skill of blindfolded adults, though boys showed individual variation in proportionate decrement by blindfold not shown by adults. Results suggest greater proportionate emphasis upon visual spatial coordinations by adults than by boys of mean age 4:9 perhaps due to differential maturation or to relative educability of structures concerned in reciprocal influences governing equilibrium. Need for evidence as to eye fixation is indicated.

7. One-hundred-per-cent retention after an interval of 3½ months was recorded by an adult and a 5-year-old boy, the latter in three trials making a 2-per-cent gain over former best efforts. After the same period, a 12-year-old girl, who had changed to higher heels meantime, showed loss in efficiency and reversal of sidedness.

8. Control of attention by extraordinarily careful elimination of distraction, particularly by sound, is indicated. Experimental control of attention by lighting effects appears fruitful.

9. Individual qualitative differences in pattern of reaction were marked. Freedom of movement with increased activity appears to bring out a greater variety of combinations and thus to tend toward greater skill in a way not solely related to speed of reaction. In-

tegrated movement apparently associated with less effort tends to accompany control in equilibration. Extreme body and limb contractions, distal contractions and other extraneous tensions appear more noticeable in less skilled performance.

10. Data from an extended learning series indicate a perhaps slight positive relationship to bodily nutrition. This fact may point toward a hypothesis that optimal neuromuscular learning is associated with optimal nutrition as affecting chemical balance of muscle cells and circulating fluids.

From the data of the present experiment the balancing-board is believed to show definite value for the study of: (1) age increase in ability in equilibration; (2) adult sex differences in equilibrium; (3) sidedness; (4) influence of visuo-motor reflexes on equilibration; (5) differential functions controlling equilibrium; (6) differential maturation of structures influencing equilibrium; (7) retention; (8) attention; (9) functional efficiency of neuromuscular mechanisms as referable to optimum chemical balance of the structures participating.

VI

SUGGESTIONS FOR FURTHER STUDY

Suggestions for further study include the following modifications:

1. Improvement of the apparatus by mechanical summation of records and device for measuring force of descent on each side.

Dr. Dunlap has now designed and built a second balancing-board which moves on ball bearings, is capable of correction to a fine point of balance, and, by vertical adjustment of the board's surface with reference to the axis, can provide a close gradation of ease in performance.

2. Control of visual cues by means of early reduction and later training by stationary device. Investigation of effects of eye fixation and of distraction by visual means.

3. Inclusion of at least ten trials in work with any one variation.

4. Pairing or other means of control of factors of chronological age, sex, intelligence, nutritional status, and socio-economic level. Holding of chronological age of children under six years to a one, or not more than a two, months' range.

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L'APPRENTISSAGE MOTEUR DES ENFANTS EN ÉQUILIBRE PAR RAPPORT À LA NUTRITION

(Résumé)

En employant une planche d'équilibre, on a fait une étude exploratrice de l'apprentissage moteur avec équilibre du corps par rapport à la nutrition. On a suivi un programme étendu d'apprentissage avec des variations des stimuli, en employant dix enfants âgés en moyenne de 4 ans et 8 mois. Pour une comparaison on a fait subir la série à cinq sujets plus âgés de divers âges. On présente les résultats de ce petit nombre de sujets comme tentatifs et seulement indicatifs, non comme conclusifs.

1. Entre l'âge de 23 ans et celui de 4 ans, 8 mois, un accroissement lent et un peu irrégulier de la capacité de tenir l'équilibre avec peut-être un accroissement plus rapide de 6 à 8 ans est indiqué. Dans 24 épreuves les adultes ont gagné plus de pourcentage que les enfants de l'âge moyen de 4 ans, 8 mois.

2. Les différences de sexe ont été négligeables sauf qu'il y a eu de l'évidence d'une plus grande variabilité chez les filles.

3. La préférence de côté est indiqué par la plus grande capacité, mais variable, du côté droit du corps. Une différence probable du contrôle fin de la descente sur les deux côtés paraît. Des différences individuelles quant à la quantité et à la sorte de l'effet des coordinations spatiales visuelles sur la préférence de côté se montrent. La préférence de côté peut se changer au moyen des réflexes visuels. Les habitudes adultes de préférence de côté, nouvelles, paraît-il, peuvent persister pendant trois mois sans exercice spécifique.

4. L'essai de contrôler les repères visuels est accompagné d'une tendance à une plus grande vitesse d'amélioration, bienque le mouvement de l'appareil pour un tel contrôle a des imperfections. On peut expliquer un tel progrès par la modifiabilité des réflexes spatiaux visuels.

Les garçons aux yeux bandés ont souffert une plus petite perte proportionnée de capacité que les adultes aux yeux bandés. Les garçons aux yeux bandés ont retenu une partie de l'accroissement gagné dans l'apprentissage des séries; les adultes aux yeux bandés ont perdu cet accroissement et plus.

Les garçons aux yeux bandés ont égalé les adultes aux yeux bandés en habileté, ce qui suggère que les adultes appuient plus proportionnément sur les coordinations spatiales visuelles. Un besoin de l'évidence sur la fixation des yeux est indiqué.

5. Une rétention de cent pour cent après l'intervalle de 3½ mois, a été enregistrée par un adulte et un garçon âgé de 5 ans.

6. Les différences individuelles qualitatives dans la forme de la réaction ont été marquées.

7. Les données de la série étendue d'apprentissage indiquent peut-être une légère relation positive à la nutrition du corps. Cette suggestion peut indiquer une hypothèse que l'apprentissage neuromusculaire optimal est associé à la nutrition optimale dans l'influence sur l'équilibre chimique des cellules musculaires et les fluides circulants.

D'après les données ci-dessus, la planche d'équilibre paraît de valeur pour l'étude de l'équilibre à l'égard: (1) de l'accroissement de l'habileté avec l'avancement de l'âge, (2) des différences adultes de sexe, (3) de la préférence de côté, (4) de l'influence des réflexes visuels-moteurs, (5) des fonctions différentielles de contrôle, (6) de la maturation différentielle des

structures qui influent, (7) de la rétention, (8) de l'attention, (9) de l'efficience fonctionnelle du mécanisme neuromusculaire par rapport à l'équilibre chimique optimum des structures qui y participent.

BEEBE

DAS LERNEN VON KINDERN IM BEREICH DER GLEICHGEWICHTSERHALTUNG IN DEREN BEZIEHUNG ZUR ERNÄHRUNG

(Referat)

Die Verfasserin machte eine forschende Untersuchung des motorischen Lernens im Bereich der Gleichgewichtserhaltung (Äquilibrierungsfähigkeit) [body balance], in deren Beziehung zum Ernährungszustand, unter Verwendung eines Schaukelbrettes [balancing board]. Es wurde ein weitreichendes Lernprogramm, mit variirenden Reizen, an zehn Kindern ausgeführt, deren durchschnittliches Alter 4 Jahre 8 Monate betrug. Zum Vergleich machten auch 5 ältere Versuchspersonen verschiedenen Alters die Prüfungen durch. Folgende, an nur wenigen Vpp. ermittelten Befunde werden als vorläufige, nur wegweisende, nicht als endgültige angegegen.

(1) Zwischen 23 Jahren und 4 Jahren 8 Monate wird eine langsame, etwas unregelmässige Zunahme der Gewandtheit bei der Gleichgewichtserhaltung [skill in equilibrium], vielleicht mit einer etwas rascheren Zunahme zwischen 6 und 8 Jahren, angedeutet. In 24 Versuchen erwiesen Erwachsene prozentmässig grössere Zunahmen als Kinder im Durchschnittsalter 4 Jahre 8 Monaten. (2) Geschlechtsunterschiede waren im Allgemeinen unbedeutend; nur erwiesen sich die Mädchen etwas unbeständiger, als die Knaben. (3) Bevorzugung einer Körperseite [sidedness] zeigte sich darin, dass die rechte Seite gewandter, aber auch variabel war. Es besteht vermutlich ein Unterschied zwischen den beiden Seiten in Bezug auf die Feinheit der Beherrschung des Herabsteigens. Es werden individuelle Unterschiede erwiesen, in Bezug auf die Art und Wievielheit der Einwirkung visueller räumlicher Koordinationen auf die Bevorzugung einer Körperseite. Diese Bevorzugung lässt sich durch visuelle Reflexe ändern. Eine scheinbar neu erworbene, erwachsene Bevorzugungs Gewohnheitsart [adult habit of sidedness] kann ohne spezifische Einübung drei Monate lang weiter bestehen. (4) Der Versuch, visuelle Anweisungen zu beherrschen [control of visual cues] geht mit etwas Beschleunigung der Leistungsverbesserung einher, obwohl der beweglichen Einrichtung [device] zur Erzielung dieser Beherrschung gewisse Fehler innewohnen. Eine solche Beschleunigung ist vielleicht auf Modifizierbarkeit der visuellen räumlichen Reflexe [spatial reflexes] zurückzuführen. Knaben mit verbundenen Augen büsten relativ weniger an Gewandtheit ein, als Erwachsene mit ebenfalls verbundenen Augen. Knaben mit verbundenen Augen behielten einen Teil der in der Lernseries erzielten Besserung. Die Erwachsenen mit verbundenen Augen büsten diese Zunahme, und noch mehr, ein. (5) Knaben mit verbundenen Augen standen in Bezug auf Gewandtheit Erwachsenen mit verbundenen Augen zur Seite. Hierdurch wird auf eine relative stärkere Betonung der visuellen räumlichen Koordinationen durch Erwachsene hingewiesen. Es mangelt an Befunden in Bezug auf die Augenfixierung [eye fixation], die vielleicht hier nützlich sein würden. (6) Nach 3½ Monaten hatten noch ein Erwachsener und ein 5-jährigen

Knabe die völlige angeeignete Gewandtheit [100% retention]. Es bestanden starke qualitate Unterschiede zwischen den individuellen Reaktionsweisen. Befunde aus ausgedehnten Lernserien weisen vielleicht auf eine geringe positive Beziehung zu dem körperlichen Ernährungszustand hin. Durch diese Hinweisung wird vielleicht die Hypothese angedeutet, dass eine Beziehung besteht zwischen der optimalen neurologischen Lernfähigkeit und dem optimalen Ernährungszustand, in so fern, als diese Beziehung das chemische Gleichgewicht der Muskelzellen und der zirkulierenden Flüssigkeiten beeinflusst.

Auf Basis der vorhergehenden Befunde erweist sich das Schaukelbrett bei der Untersuchung des Gleichgewichts wertvoll in Bezug auf: (1) Zunahme der Gewandtheit mit zunehmendem Alter; (2) Geschlechtsunterschiede bei Erwachsenen; (3) Bevorzugung einer Körperseite; (4) Einwirkung visuo-motorischer Reflexe; (5) differenzierende kontrollierende Funktionen; (6) differenzierende Reifungsgrade der einwirkenden Strukturen; (7) Beibehaltung [retention]; (8) Aufmerksamkeit; (9) funktionelle Leistungsfähigkeit des neuromuskulären Mekanismus in dessen Beziehung zu dem optimalen chemischen Gleichgewicht der teilnehmenden Strukturen.

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DISCRIMINATION LIMENS OF PATTERN AND SIZE IN THE GOLDFISH *CARASSIUS AURATUS**

From the Animal Laboratory of the Department of Psychology, Columbia University

By

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POUGHKEEPSIE, NEW YORK

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I

INTRODUCTION

Limens for visual discrimination of pattern and size have been found for very few species of animals. In most experiments involving differential response to visual stimuli, the differences in the stimuli used are well above the limen for the subjects being tested. Results obtained from these studies do, however, give some information regarding the acuity of vision of the animals trained, and, in a few instances, indicate the limits of discriminative ability.

The only attempt to establish visual limens for primates is Johnson's (15) work with a Cebus monkey. He used illuminated fields on which were striae of different widths produced by two pairs of superimposed gratings. The monkey could distinguish differences in width of striae of less than 3%. The standard stimuli in the different tests varied from striae .173 mm. to 1.56 mm. in width. By a similar method (16), it was found that the monkey could distinguish a striped field from a uniform field when the visual angle subtended by the individual striae was 57″. These results are similar to those found for human beings.

Under the same conditions a dog failed to discriminate between the two fields although the stripes were made nearly six times as wide (15). The dog could distinguish a circle 6 cm. in diameter from circles 1, 2, and 3 cm. in diameter when the intensity of the light transmitted through the pairs of circles was constant; but not from circles 4 cm. and 5 cm. in diameter. When

the circles were equated for brightness, discrimination between the 6-cm. and the 3-cm. circles broke down. In the experiments of Shenger-Krestovnika (20) a dog was trained to discriminate between a circle and an ellipse. By using a series of ellipses gradually approaching the circle in form it appeared from repeated tests that the limit of discrimination was reached when the ratios of the semi-axes were slightly more than 9:8.

Little work has been done on visual limens in other mammals. Hadley's (8) experiments with guinea pigs showed their ability to discriminate between squares of different sizes. The least difference reported was between a square 3 in. on a side and a square 1 in. on a side. Working with white rats, Lashley (18) found that they could discriminate between a circle 3 cm. in diameter and one 5 cm. in diameter, and between a square 1 cm. on a side and a square 12 cm. of a side. With one rat the discrimination continued when the circles were 5 cm. and 4 cm. in diameter.

Visual stimuli have been used extensively in the study of birds, although few attempts have been made to establish limens. Révész' (24) experiments with hens showed that they could detect a difference between a circle 9.5 cm. in diameter and one 8 cm. in diameter, between a square 6.3 cm. on a side and one 5 cm. on a side, between a triangle with a base 7.5 cm. and an altitude 6.5 cm. and a triangle with a base 6 cm. and an altitude 5.3 cm., and between a parallelogram 4 x 8.5 cm. and one 4 x 7.5 cm. More controlled experiments by Bingham (1) measured the smallest difference in size of circles that could be distinguished by chicks.

One chick detected a difference between a 6-cm. circle and one 4.5 cm. in diameter. For seven other chicks the limen was slightly higher. Bingham concludes that the threshold for discrimination, using a 6-cm. circle as standard, is a circle from 1/4 to 1/6 larger. Under the same conditions the limen for a human was a circle 1/12 larger than the standard. Johnson (15), using the method previously described (p. 251) for studying the effective difference in width of visible striae, found that a chick "ceased to discriminate when the difference in width of striae was reduced to a value between 38% and 42%." The width of the standard striae in the tests varied from .74 mm. to 3.12 mm. When the problem was to distinguish a plain field from a striped field, the visual angle subtended by the smallest effective striae was 4′ 04″ for one chick, 4′ 14″ for another (16). According to this measure, the chick's acuity of vision is not more than 1/4 that of the monkey. In experiments with two crows, Coburn (6) reports that, after learning to go to the larger of two circles (9 cm. in diameter and 2 cm. in diameter, respectively), they continued to go to the larger stimulus when circles of different sizes were used. They learned to discriminate correctly between circles of 3 cm. and 2 cm. diameters, 5 cm. and 4 cm., and 5 cm. and 4.5 cm. The criterion for learning was 4 or 5 correct choices when 5 trials were given daily. Stimulus differences of ratio less than 1:10 were not presented.

The visual discrimination of turtles has been studied by Casteel (4). He found that when two turtles were presented with surfaces of alternating black and white

stripes they could distinguish between the fields when the stripes were 8 mm. wide on one surface and 2 mm. wide on the other. One turtle was able to discriminate when the stripes were 3 mm. wide and 2 mm. wide. This was the smallest difference in width of stimuli used.

Previous experiments on fishes have shown discrimination of visual stimuli by a number of species. Stimuli differing in form, in brightness, or in size have been used. Goldsmith (7) trained specimens of *Gobius* and *Gasterosteus* to discriminate between different forms, food being presented when the correct stimulus was chosen. She used triangular, rectangular, circular, star-shaped, and double-pointed figures. From the results obtained, she concluded that form was a more important factor than color in determining the reaction. Maes (19) reports that the stickleback and other fishes can dissociate form and size cues from color. Schaller (25) trained minnows to go for food to a stimulus of certain form. Discrimination between circles, stars, squares, and triangles was established. The discrimination of brightness differences has been studied by Reeves (23) for dace and sunfish; and by Perkins (21) for the goldfish. Reeves' method was to vary the amount of light illuminating the stimulus plates by changing the size of the slits through which the light was admitted. She found that three dace could not distinguish differences in intensity of 1:4. Positive results were obtained with greater brightness differences. Results with three sunfish showed that differences in intensity of 1:2 were the least that could be discriminated.

Perkins (21) presents evidence for configurational learning in the goldfish, based on differences in the intensity and position of the stimuli. Combinations of three lights of varying intensities were presented at each trial. The intensities, measured in foot candles, were 10.55, 4.8, .73, .21, .018, and 0. With these differences the fishes "learned to choose one of three absolute light intensities and to transfer up and down the intensity scale without added training." In experiments on visual perception of size in fishes, Herter (11) has studied several species. His results showing the response to "similarity" or to "relative size" of stimuli give an indication of the small differences that can be perceived. After a training series in which the positive stimulus was a circle 3 cm. in diameter and the negative stimulus 1 cm. in diameter, two fishes went to the larger figure in 90% of the 60 trials given when the diameters of the stimuli were 4 cm. and 3 cm., 1 cm. and 0.5 cm., and 3 cm. and 1.5 cm., respectively. Similarly, two fishes trained to the 1-cm. circle as positive stimulus went to the smaller circle in 94% of the 60 trials given with the test stimuli just mentioned. These results indicate that the visual discrimination of size by these fishes is very good. As the problem was not primarily one of size perception, however, there are no data to show whether or not these differences between the stimulus pairs were near the threshold of discrimination.

The present experiment was undertaken in an attempt to establish limens for visual perception of pattern and size in the goldfish. In studying the discrimination of pattern, fields of alternating equal black

and white stripes were used as stimuli. It was thought at first that an adaptation of Johnson's apparatus (14) could be used for presenting the striated areas, but the construction of the stimulus plates and holder presented serious difficulties. Moreover, the striae produced on the illuminated fields by this method are not distinct. They appear "fuzzy" at all values (14). For the purpose of this experiment more decided contrast in the stripes seemed advisable. Consequently this technique was given up in favor of a modification of the method used by Casteel (4). Black stripes of the desired widths were painted with waterproof ink on white cardboard stimulus cards. These were presented in pairs. In studying the discrimination of size, illuminated circles of different diameters were used as stimuli. These were produced by means of a light-box patterned after the Yerkes-Watson apparatus. The details of the method will be discussed in the following sections. Neither of these techniques had been previously applied to fishes.

II

EXPERIMENT I

Pattern Discrimination

The problem in this experiment was to find the smallest difference in pattern of visual stimuli that could be distinguished by the goldfish. The stimuli consisted of cards bearing black and white stripes of equal widths. The stripes on the two fields were of different widths.

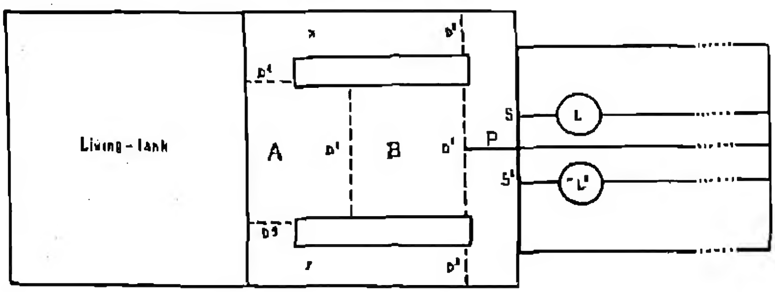
Subjects. The fishes used in this experiment were common goldfish, *Carassius auratus,* obtained from a local dealer. As subjects for experimental work this type of fish proved satisfactory, on the whole, and easy to handle. They were kept in a galvanized iron tank holding approximately 23 gallons of water. The tank was cleaned several times a week, and the water changed daily. To prevent fungus growth, the most common disease among goldfish, small amounts of common salt and of Epsom salts were dissolved in the water occasionally. All the fishes remained in good health throughout the training periods, which varied from 29 to 32 days.

Great care was taken to avoid any jarring of the tank or any change of lighting during the experiment, as the fishes were extremely sensitive to disturbances of this kind. When a fish was frightened it remained practically motionless for periods as long as two hours, although no further external disturbance occurred. Work was begun with 10 fishes, but, because of their

almost complete inactivity, 4 were discarded after various intervals as unfit for experimental work. The others soon became used to the experimental conditions and moved freely and quickly about the tank and discrimination apparatus. Two fishes (No. 1 and No. 3) were trained to go to the card bearing the narrower stripes. For the remaining fishes (No. 2, No. 4, No. 5, and No. 6) the positive stimulus was the card bearing the wider stripes.

FIGURE 1

DIAGRAM OF THE LIVING-TANK, DISCRIMINATION APPARATUS, AND LIGHT-BOX



A—detention compartment
B—choice compartment
D[1], *D*[2], *D*[3], *D*[4]—doors
P—partition
L, *L*[1]—lights
S, *S*[1]—positions of stimuli

Apparatus. The discrimination box was placed at one end of the large tank which served as living-quarters. The type of apparatus used is shown in Figure 1. The box was made of wood, and painted a medium shade of gray. The floor of the apparatus was approximately 20 cm. above the bottom of the tank, and the walls of the apparatus extended 1 cm. above the surface of the water. The dimensions of the box were as follows: height of walls, 8 cm.; detention compart-

ment, 5 cm. x 11½ cm.; choice compartment, 9 cm. x 11½ cm.; length of partition between stimuli, 10 cm.; width of alleys, 5 cm. The water in the apparatus was 7 cm. deep. The doors which separated the various compartments were raised above the surface of the water when a fish was to be allowed to pass from one part of the box to another. These doors were manipulated by means of strings stretching across the top of the living-tank to the end nearest the experimenter. The experimenter was separated from the discrimination apparatus and tank by a screen of black cloth. Observations were made through a small window cut in the screen.

The room in which the experiment was conducted received light from a north window and a skylight. Two electric lights in the ceiling of the room were lighted during the tests. The illumination, measured by a Westinghouse Foot Candle Meter, was approximately 20 foot candles.

The stimuli were exposed at S and S' (see Figure 1). They were made of heavy white cardboard, on which horizontal stripes were painted with black waterproof ink. Cards 5.5 cm. x 8 cm. were placed on the end wall of the apparatus, and smaller cards, 4.5 cm. x 8 cm., were placed on the floor directly in front of the vertical stimuli. These smaller cards were held in position by pieces of metal which covered the backs and were bent about ¼ in. over the edges of the cards. A great number of duplicate sets of stimuli were made, so that any one set was used not more than four or five times. The cards were changed during each day's

tests to avoid possible sources of error due to differences, other than width of stripes, in the stimuli.

Procedure. To enter the discrimination box the fishes had to rise toward the top of the tank and swim through a door (7 cm. x 12 cm.) at one end of the apparatus. This door was kept closed at all times except when a fish was being let in or out of the discrimination box. At first, the fishes were guided toward the door by means of a wire scoop; but after a short time the experimenter's problem changed from that of guiding one fish in the direction of the door, to that of keeping all the fishes from going into the discrimination box whenever the door was opened. This was accomplished by the use of wire screens so placed that only the fish to be experimented upon had access to the door of the apparatus. A fish was detained in compartment *A* for approximately one minute before the door leading to the choice compartment was opened. As soon as a fish had passed into compartment *B*, the door of the detention compartment was closed again. A fish had then to go either to the left or right of the partition, and as soon as a choice was made door D^2 was closed to prevent return to compartment *B*. Alleys *X* and *Y* led back to the detention compartment. Doors D^3 and D^4 were closed as soon as a fish had passed these points.

For two or three days preliminary to beginning training, several fishes were put into the apparatus together for an hour at a time. All the doors in the discrimination box were left open so that the fishes could swim freely from one part of the apparatus to another and food was placed at various points on the floor. After

having become familiar with the apparatus to this extent, each fish was put into the discrimination box alone. The procedure in this case was the same as that to be used in the training, with the exceptions that no stimulus cards were used and that food was placed on the floor at the points where the reward was to be given during the experiment. The food consisted of pellets of French's Prepared Food for Fishes. The fish was kept in the apparatus until it had discovered and eaten the food. This took from 3 to 10 minutes on the first day, but thereafter not more than 5 seconds. In the whole experimental period there were only four or five instances in which the food was overlooked or not eaten. This preliminary procedure was repeated for three days with each fish.

In the training series no punishment was given, but food was used as incentive. After a correct choice had been made and the door D^2 closed, the experimenter moved a lever at the side of the apparatus by which one pellet of food was dropped into the water at a point approximately 11 cm. to the side of the stimulus and 4 cm. in front of the wall on which the cards were exposed. The pellets were of sufficient weight and were dropped from sufficient height to cause them to sink to the floor of the apparatus at once.

Since reward alone was used, it was important to keep the hunger drive as constant as possible from day to day so that the incentive would be consistently effective. For this reason the usual procedure of giving a certain number of trials daily, regardless of whether the responses are correct or incorrect, was not used. In

place of this, each day's training was continued until a certain number of *correct* choices had been made, thus making sure that a certain amount of food (reward) was received.

Approximately 2 minutes were necessary for the experimenter to adjust the apparatus and arrange the stimuli. The successive trials followed each other after this interval. The right-left position of the stimulus cards was determined by chance, with the exception that the positive stimulus was never presented on the same side more than four times in succession. At the beginning of the training period the day's testing was continued with each fish until four correct choices had been made. This procedure was carried out for the first 80 trials. During this time the responses came to be made much more quickly than at the beginning of the experiment. In all the later training the number of correct choices required each day was increased to *five*.

The habit of going always to the stimulus presenting the pattern of wider (or narrower) stripes was thoroughly established by training to the stimuli of greatest difference until 24 out of 25 correct successive responses were made. For discrimination between the other stimulus sets this amount of training was not considered necessary. The criterion of learning in all other tests was 9 out of 10 successive correct responses.

Results. The pairs of stimuli used in the training series in this experiment are shown in Table 1. Two fishes were trained to the stimulus pattern of narrower stripes; four fishes, to the pattern of wider stripes.

TABLE 1

SHOWING THE STIMULUS SETS USED IN THE TRAINING SERIES

The width of the stripes in each set is expressed in millimeters.

	Stimulus set									
	A	B	C	D	E	F	G	H	I	J
Positive stimulus	2	3	5	3	7	5	10	10	10	10
Negative stimulus	10	10	10	7	10	7	2	3	5	7

TABLE 2

SHOWING THE NUMBER OF FISHES LEARNING TO DISCRIMINATE EACH STIMULUS DIFFERENCE

The differences in widths of stripes are expressed in millimeters.

	Difference in width of stripes					
	8	7	5	4	3	2
Number of fishes trained	6	4	6	1	4	1
Number of fishes learning	6	4	4	1	1	1

The differences in stimulus patterns that were discriminated after training appear in Table 2, with the number of fishes learning each discrimination. Table 3 shows the progress of learning during the training with the various widths of patterns. The percentage of correct responses in each series of 20 trials is given. The number of errors, even at the beginning of the training, was small in every case. Twenty trials include data from not more than 5 days' testing; and, for the latter part of the training, for only 4 days' testing. With a choice between two stimuli in each trial, and only 4, or at most 5, choices daily, the number of errors even in a series of random responses would naturally not be large. The fact that no punishment was given in connection with incorrect choices is probably responsible for the relatively slow dropping-out of er-

TABLE 3

SHOWING THE PERCENTAGE OF CORRECT CHOICES FOR EACH FISH PER 10 TRIALS

The trial at which each stimulus set was introduced in the training series is indicated by the number in parenthesis.

Trials	Stimulus set	Fish No. 1	Stimulus set	Fish No. 2	Stimulus set	Fish No. 3	Stimulus set	Fish No. 4	Stimulus set	Fish No. 5	Stimulus set	Fish No. 6
1-10	A	80	G	40	A	80	G	50	G	80	G	90
11-20		40		30		60		40		90		50
21-30		100		50		70		70		60		70
31-40		70		70		60		70		70		60
41-50		80		50		70		60		90		80
51-60		70		80		70		80		50		70
61-70		80		80		90		80		90		100
71-80		70		80		90		80		100		90
81-90		80		80		100		70		90	H (87)	100
91-100		90		80	B (95)	100		90	H (94)	90	I (97)	80
101-110		100		90	C (105)	100		100	I (105)	80		100
111-120	C (115)	100		100	D (111)	90	H (116)	100		50	J (120)	70
121-130	E (126)	90	I (123)	90		90	I (126)	80		80		50
131-140		70		90	E (131)	80		70		70		70
141-150		70		90		100		70		50		50
151-160		70		100	F (158)	90		60		60		60
161-170		60	J (161)	70		100		70		60		
171-180		60		60				60				
181-190				70								
191-200				50								

rors. The daily records for each fish show a fairly even distribution of errors among the four or five trials given. A comparison of the records according to the order in which the fishes were tested each day shows no significant difference in the number of errors made by

those whose trials came at the beginning and those whose trials came at the end of the day's testing. Any traces of food resulting from the dropping of the pellets into the water were obviously too slight to act as cues for subsequent responses.

TABLE 4

SHOWING THE NUMBER OF ERRORS FOR RIGHT AND LEFT POSITION OF THE POSITIVE STIMULUS

		Fish											
		No. 1		No. 2		No. 3		No. 4		No. 5		No. 6	
Trials	Positive stimulus	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors
1- 50	Right	17	8	13	12	16	9	17	9	19	7	19	8
	Left	20	5	11	14	18	7	12	12	20	4	16	7
51-100	Right	19	8	17	5	20	3	17	6	23	6	21	4
	Left	20	3	23	5	25	2	23	4	19	2	23	2
101-150	Right	23	4	22	2	27	1	20	5	15	11	15	7
	Left	20	3	24	2	19	3	22	3	18	6	19	9
151-200	Right	5	2	13	7	5	1	8	4	5	3	0	3
	Left	8	9	16	8	6	0	8	7	4	5	0	1
Total	Right	64	22	65	26	68	14	62	24	62	27	55	22
	Left	68	20	74	29	68	12	65	26	61	17	58	19

The distribution of errors according to the right-left position of the positive stimulus is shown in Table 4. No persistent place habits appeared during the course of the experiment. The record of fish No. 5 shows a considerably greater number of incorrect choices when the positive stimulus was on the right side. In the other five cases, however, the difference in number of errors for the two positions of the positive stimulus is very slight.

TABLE 5

SHOWING THE NUMBER OF TRIALS REQUIRED TO ESTA
DISCRIMINATION WITH EACH STIMULUS SET

The differences in width of stripes are expressed in millimete:
indicates failure to learn in the number of trials given.

		Trained to narrower stripes			Trained to wider stripes		
Difference in width of stripes	No. tested	Fish No. 1	Fish No. 3	Fish No. 2	Fish No. 4	Fish No. 5	F
8	6	86	67	97	89	65	(
7	4		0		0	0	
5	6	0	0	28	F51	F62	
4	1		0				
3	4	F47	10	F31			F:
2	1		10				

The number of trials required before perfect crimination with each of the stimulus sets is shov Table 5. All of the fishes trained with the stin sets differing by 8 mm. in width of stripes learne discrimination. The number of trials required b satisfying the criterion of 24 out of 25 successive cc responses ranged from 60 to 97. The average nu of trials before perfect discrimination was 77, r senting roughly 13 days' training. The two trained to the pattern of narrower stripes require proximately the same number of trials to learn a the four fishes trained to the pattern of wider st One of the two learned in 10 fewer trials than th erage for the other group; one learned in 9 more than this average.

Perfect discrimination continued in all cases

the difference in width of stripe on the two fields was reduced from 8 mm. to 7 mm. A further reduction to a difference of 5 mm. caused errors in 4 of the 6 cases. Two of the fishes that were at first disturbed by this change of stimuli learned the discrimination after further training. One fish (No. 5) showed no increase in number of correct responses in 62 trials; another fish (No. 4) gave no evidence of learning in 51 trials.

Of the 4 fishes tested with stimuli of smaller differences in pattern, only one learned the discrimination. The record of this fish (No. 3) is exceptional. Throughout the experiment it proved to be the most satisfactory subject. It required no additional training to establish discrimination when the stimulus sets B, C, and D were introduced. After making 2 errors in the first 10 trials with set E (a difference of 3 mm. in width of stripes), 10 correct responses were made. Similarly, after 1 error with stimulus set F (a difference of 2 mm. in width of stripes), 9 out of 10 correct responses were made. After every two trials with these stimulus sets new stimulus cards were introduced in order to eliminate the possibility of secondary cues. From the results it appeared that the discrimination was not based on any difference of this kind in the stimuli, but on the difference in the patterns of the two fields.

The average time for choice (until the fish had gone sufficiently far on one side of the partition to allow door *D* to be closed) is shown in Table 6. The average choice time for all trials was 18.7 seconds. A comparison between the average time taken in the first 50 trials

TABLE 6

SHOWING THE AVERAGE TIME IN SECONDS FOR CHOICE FOR EACH FISH PER 10 TRIALS

The trial at which each stimulus set was introduced in the training series is indicated by the number in parenthesis.

Trials	Stimulus set	Fish No. 1	Stimulus set	Fish No. 2	Stimulus set	Fish No. 3	Stimulus set	Fish No. 4	Stimulus set	Fish No. 5	Stimulus set	Fish No. 6
1-10	A	86.9	G	106.4	A	48.0	G	24.1	G	77.8	G	70.7
11-20		16.8		15.3		31.0		13.2		74.8		154.8
21-30		31.4		59.8		37.1		16.5		45.5		144.7
31-40		14.6		55.0		59.2		12.6		19.8		69.1
41-50		27.6		27.6		13.3		6.9		13.4		34.1
51-60		10.0		13.3		12.4		5.9		26.3		19.8
61-70		5.7		17.5		19.0		4.1		22.2		7.0
71-80		4.0		10.2		18.4		2.9		13.6		5.6
81-90		3.5		17.2		18.5		3.7		6.5	H (87)	4.0
91-100		3.0		13.6	B (95)	8.7		2.9	H (94)	6.9	I (97)	2.8
101-110		3.4		8.0	C (105)	14.7		2.1	I (105)	6.8		2.9
111-120	C (115)	3.4		14.4	D (111)	10.5	H (116)	2.8		10.7	J (120)	8.5
121-130	D (126)	2.9	I (125)	7.2		5.9	I (126)	3.1		5.0		4.0
131-140		2.4		13.9	E (131)	11.7		5.1		5.6		3.5
141-150		2.7		6.8		12.6		2.5		5.5		3.6
151-160		2.2		4.2	F (158)	7.0		7.0		4.8		2.7
161-170		1.8	J (161)	4.2		3.5		2.9		5.1		
171-180		3.3		3.4				7.4				
181-190				3.7								
191-200				3.2								

and the average time taken in the latter part of the training shows a very decided speeding-up of the reaction (see Table 7). This is also apparent in the time

TABLE 7

SHOWING THE AVERAGE TIME IN SECONDS FOR CHOICE FOR EACH FISH PER 50 TRIALS AND THE AVERAGE TIME FOR ALL RESPONSES, FOR CORRECT RESPONSES AND FOR ERRORS

Trials	Fish No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
1- 50	35.4	48.8	33.7	14.6	46.0	94.7
51-100	4.8	14.3	12.4	3.9	15.0	7.8
101-150	2.9	10.0	11.0	2.7	6.7	4.5
151-200	2.4	3.7	5.2	5.8	4.9	2.7
Total, av.	12.8	19.7	19.0	6.9	20.8	34.8
Correct, av.	13.7	17.0	15.5	6.5	20.2	29.3
Errors, av.	8.8	27.0	39.4	7.9	23.2	59.6

for total response (from entrance into compartment *B* to return to compartment *A*). The average time for the first 50 trials for all the fishes was 211 seconds. The average time for the last 50 trials was 43 seconds.

When the difference in width of stripes of the stimulus cards was reduced to 7 mm. there was no increase in the amount of time taken before making a choice. A further decrease to a 5-mm. difference did not affect the discrimination time. But the introduction of the stimulus sets with smaller differences between the patterns increased the discrimination time in every case for the trials immediately following the change in stimuli.

If the time for correct responses is compared with the time for incorrect responses, it appears that in 5 of the 6 cases the average time for correct choices was shorter than the average time for errors (see Table 7).

In the record of fish No. 3 there are 88 chances in 100 that the difference represents a true difference; but in no case is the difference between the averages statistically reliable as measured by the standard error of the difference. In those trials in which a fish was "inattentive," i. e., failed to look at the stimulus cards, it first swam about in the compartment *B* for some time, then out on either side of the partition. Under these circumstances, of course, the "discrimination" time was long, and the chances that the response would be a correct one were 50-50. On the other hand, when the fish "attended" to the stimulus, i. e., looked at it, it reacted quickly; and these responses were more often right than wrong. The average time, then, for all correct responses would tend to be less than the average time for errors. The total reaction-time does not show this difference in speed between correct and incorrect responses. In 3 cases the latter was the slower response; in 2 cases it was quicker; and in one case there was no difference between the two types of reaction. The average time for total response after correct choice was 73.7 seconds; after errors, 82.5 seconds. These results may be explained by the fact that some of the fishes making correct choices, after finding the food, remained in the same spot to eat it before returning to the detention compartment, making the total time long. On the other hand, some fishes that made wrong choices swam back and forth near the point at which food was dropped when reward was given, and thus delayed their return to compartment *A*.

In some trials the response seemed to the experiment-

er to show an unusual amount of hesitation. The fish would start swimming rather rapidly toward one stimulus, stop, appear to look at it carefully, and then proceed; or the fish would swim back and forth several times in front of the stimuli before making a choice. These appeared to be not merely random movements, but directly related to the discriminative response. In the daily records note was made of the number of responses showing this hesitation. The number varied greatly with the individual fishes. They were, on the average, 15 seconds longer than the average for all choices, and were distributed fairly evenly throughout the trials with each pair of stimuli. In every case, as is shown in Table 8, more of these responses after hesitation were correct than were incorrect. Comparing the ratio of correct to incorrect responses in the trials showing hesitation to the ratio of correct to incorrect responses in trials without hesitation, it appears that for 4 of the 6 fishes the proportion of errors is less in the trials with hesitation. This does not contradict the

TABLE 8

SHOWING THE PERCENTAGE OF CORRECT AND INCORRECT CHOICES AFTER HESITATION

	Fish					
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6
Total trials	174	194	162	177	167	154
% of trials showing hesitation	6.9	10.3	25.3	1.6	20.9	16.2
% incorrect after hesitation	8.0	15.0	12.0	33.0	25.0	4.0
% incorrect without hesitation	19.0	29.0	16.0	25.0	17.0	20.0

previous statement that correct choices were, on the average, faster responses than those in which errors were made. Among the slow reactions were many that did not fall into this group that seemed to the experimenter to show hesitation, the delay in these cases being due merely to the fish's prolonged and random swimming about in compartment *B*, without reference to choice of stimuli. The fishes showing the greatest number of responses with hesitation were also those having the highest average time for correct response.

The results of the experiment show that the goldfish can be trained to discriminate between patterns of varying widths of stripes. The differences perceived were similar to those discriminated by turtles in Casteel's (4) experiments in which stimulus patterns of the same type were used. A difference of 8 mm. in width of stripes was discriminated by 6 fishes. A difference of 5 mm. was discriminated by 4 fishes. One fish chose the pattern of narrower stripes when the difference in width was only 2 mm. These results indicate a high degree of visual acuity. To obtain a more exact measure of the limits of discriminative ability, certain modifications in the stimuli seemed advisable. In place of the fields of black and white stripes, uniform fields which could be varied in size and in brightness were used as stimuli. The limens for discrimination under these conditions were tested in Experiment II.

Before bringing the first experiment to a close, each fish was given 15 trials (3 days' training) with the stimulus pair used in the original training. The difference in width of stripes was 8 mm. The tests were then dis-

continued for 30 days. At the end of this time a retest was given, using the same stimulus pairs, and rewarding all responses. In 4 cases the discrimination was made perfectly in the first 10 trials; in one case 1 trial, and in another case 4 trials were required before satisfying the criterion of 9 out of 10 correct responses. These results indicate a high degree of retention of the discrimination habit established during the training period.

III

EXPERIMENT II

Size Discrimination

The problem in this experiment was to find the smallest difference in size of visual stimuli that could be discriminated by the goldfish. The stimuli consisted of circles of different area and of variable brightness values.

Subjects. Thirteen fishes were used in this experiment. Training was begun with one other fish, but it proved too inactive for experimental work. With three exceptions the fish remained in good health throughout the training periods, which varied from 50 to 115 days. One fish became sick after three months' training and had to be discarded. Two fishes died before the experiment was completed, one after 3½ months' training, one after 4 months'.

Apparatus. The discrimination box was similar in plan to that used in Experiment I (see Figure 1), but all compartments and alleys were made larger in order to adapt them better to the swimming movements of the fishes. The dimensions of the apparatus in this experiment were as follows: height of walls, 14 cm.; detention compartment, 14 cm. x 17 cm.; choice compartment, 15 cm. x 17½ cm.; length of partition between stimulus plates, 7 cm.; width of alleys, 7 cm. The water in the apparatus was 12 cm. deep. The length of the partition between the stimuli was decreased so that the choice could be made at a shorter distance from

the circles. In this experiment, however, as in the preceding one, the fishes apparently made the discrimination at a distance of about 12 cm. from the stimuli. The doors in this apparatus, instead of being raised above the surface of the water to permit free passage (as in Experiment I), were dropped through slits in the floor of the box, eliminating shadows in the part of the apparatus into which the fish was to move.

A section of plate glass was put into the end of the tank against which the discrimination box was placed, permitting the presentation of stimuli from outside the tank. A light-box, 1 meter long, 7 cm. high, and 15 cm. wide, was fitted into a wooden frame at this end of the tank (see Figure 1). The only light which came into the discrimination apparatus at this end was that which came through the opal flashed glass front of the light-box. This box was divided lengthwise into two parts, in each of which was a 25-watt frosted Mazda lamp. The position of the lamps could be varied from 5 to 95 cm. from the stimulus plates. The lamps used in this part of the apparatus were changed from time to time throughout the experiment.

The stimulus plates were made of brass. In each plate were cut three holes, the center hole being of the size of the positive stimulus to be used in the training. The other two holes were of equal size, either smaller or larger than the standard. These plates, placed at the end of the light-box, exposed through the plate glass end of the discrimination box lighted areas of opal flashed glass. The holes in the stimulus plates were spaced in such a way that when the plate was in

position only two lighted areas could be seen, the holes being centered in front of the two divisions of the light-box. By pushing the plate to the left or right the position of the standard stimulus could be changed from left to right, and at the same time a second circle was exposed on the other side of the partition which divided the stimulus areas. The distance between the centers of the circles thus presented was 7 cm.

During the experiment the whole apparatus was enclosed in black screening, extending approximately 80 cm. above the top of the tank. The screening was put into place an hour before the testing was to begin, and removed when the testing for the day was over. From the roof of this covering, directly over the center of the discrimination box and 80 cm. from the top of the tank, hung a 25-watt frosted Mazda lamp. This was lighted whenever the screening was in use. Observations were made through an opening in the screening at the end of the tank farthest from the stimuli.

Procedure. The fishes were divided into two groups. The 6 fishes in Group 1 (Nos. 1, 2, 3, 4, 5, and 6) were trained to go to the smaller circle. The 7 fishes in Group 2 (Nos. 7, 8, 9, 10, 11, 12, and 13) were trained to go to the larger circle. For each group, after a preliminary training with circles 2 cm. in diameter, the positive stimulus was 3 cm. in diameter.

For 3 fishes in Group 1 (Nos. 1, 2, and 3), and for 3 fishes in Group 2 (Nos. 7, 8, and 9), the daily procedure was the same as that described in Experiment I. For the other fishes in both groups the same num-

ber of trials was given daily, but, instead of having the trials in quick succession (approximately two minutes apart), the fishes were returned to the living-tank after each correct choice. The next trial was given after an interval of approximately 7 minutes.

The number of correct choices required in each day's test for the first 80 trials was three. After this amount of practice, the number was increased to four. This procedure was continued for the next 120 trials, but, on account of the amount of time required for this method, the number was again changed to three correct choices daily. This number was used in all subsequent testing.

The easiest discrimination was considered learned when the fish made 24 correct choices out of 25 responses. When this criterion had been satisfied the difference between the circles was reduced. For the remaining stimulus pairs used in training, 12 successive correct choices (*i. e.*, 3 or 4 days' testing without error) were taken as showing that the discrimination had been learned.

The position of the lights in the light-box during the training was 10 cm. from the stimulus plates. After the 5-cm. difference in diameters of circles had been discriminated correctly with the lights in this position, both lights were moved back to 20 cm. and further tests were made with the same stimulus difference. In subsequent tests with smaller stimulus differences both lights were kept in the 10-cm. position until the criterion for learning had been satisfied. Control tests were then given. In these tests the position of the lights was varied from trial to trial, one being nearer

the stimulus plates than the other. The positions of the lights during these tests ranged from 5 to 40 cm. from the stimuli. In half the tests the smaller circle was made brighter than the larger circle, the degree of brightness varying from trial to trial. These tests were continued until the fish had learned to discriminate the stimuli on the basis of size alone, regardless of the absolute or relative quantity of photic stimulation.

Results. The stimulus sets used in the training series are shown in Table 9. Six fishes were trained to go to the smaller circle; 7 fishes were trained to go to the larger circle. The differences in the size of the circles discriminated and the number of fishes learning each discrimination are shown in Table 10. In Table 11 the progress of learning during the entire training

TABLE 9

SHOWING THE STIMULUS SETS USED IN THE TRAINING SERIES

The diameters of the circles in each set are expressed in centimeters.

	Stimulus set									
	A	B	C	D	E	F	G	H	I	J
Positive stimulus	2.0	3.0	3.0	3.0	3.0	4.0	3.0	3.0	3.0	3.0
Negative stimulus	4.0	4.0	3.5	3.3	3.2	2.0	2.0	2.5	2.7	2.8

TABLE 10

SHOWING THE NUMBER OF FISHES LEARNING TO DISCRIMINATE EACH STIMULUS DIFFERENCE

The differences in diameters of circles and the distances of lights from stimulus plates are expressed in centimeters.

Difference in diameters of circles	2.0	1.0	0.5	0.5	0.3	0.3	0.2	0.2
Distance of lights from stimulus plates	10	10	10	20	10	varied	10	varied
Number of fishes trained	13	12	12	12	9	8	8	1
Number of fishes learning	12	12	12	11	9	8	2	0

TABLE 11

SHOWING THE PERCENTAGE OF CORRECT CHOICES FOR EACH FISH PER 20 TRIALS
The trial at which each stimulus set was introduced in the training series is indicated by the number in parenthesis.

Trials	Stimulus set	Fish No. 1	Stimulus set	Fish No. 2	Stimulus set	Fish No. 3	Stimulus set	Fish No. 4	Stimulus set	Fish No. 5	Stimulus set	Fish No. 6	Stimulus set	Fish No. 7	Stimulus set	Fish No. 8	Stimulus set	Fish No. 9	Stimulus set	Fish No. 10	Stimulus set	Fish No. 11	Stimulus set	Fish No. 12	Stimulus set	Fish No. 13
1-20	A	55	A	50	A	55	A	55	A	35	A	70	F	65	F	55	F	55	F	65	F	80	F	65	F	75
21-40		65		55		50		80		70		70		60		75		60		65		85		80		90
41-60		50		45		55		85		65		50		80		80		65		80		85		85		90
61-80		55		80		70		95		55		60		85	G (80)	95		90		85		90		70		100
81-100		75		95		85	B (82)	75		65		95	G (96)	90		70		80		85		90		80	G (83)	90
101-120		90	B (112)	80		95	C (120)	95		90	B (107)	90		80	H (113)	85		95		95		95		85	H (109)	90
121-140	B (131)	85		85	B (123)	65	K (132)	95		90		90	H (126)	80		80	G (128)	100	G (123)	90		80		80		95
141-160		90	C (157)	100		70	D (149)	90	B (157)	100	C (143)	100		80	N (154)	95	H (141)	80		90		95		85	N (144)	90
161-180	C (163)	90	K (169)	95		80	L (180)	95	C (169)	95	K (161)	85		90		90		80	H (178)	100		85		70		95
161-200	K (190)	90	D (186)	90	C (195)	100		90		90	D (191)	100		95	I (200)	90		90		95		90		90		90
201-220	D (216)	95		85	K (207)	95		95	K (219)	95	L (202)	90	N (202) I (214)	100	O (216)	95		85	N (203)	65	H (213)	100				
221-240	L (239)	95	L (233)	90		90	E (223)	80	D (231)	95		90		90		85	N (235)	95	I (230)	90	N (225)	85				
241-260		95		80	L (242) E (256)	95	L (256)	85		90		95	O (243)	95		95		95		90		90				
261-280	E (263)	90		90		90	E (265)	100	L (270)	95		90	J (252)	60		85	I (264)	90		90		85				
281-300	L (297)	90		90	L (291)	85		85	E (286)	90	E (283)	80		75	J (287)	85		100		90						
301-320	E (306)	85	E (313)	90	E (311)	90		90		80		90	I (320)	80		85										
321-340		85		90		95	D (330)	85		90	D (337)	85		100		85										
341-360	D (357)	85		75		95	L (349)	90			L (349)	90														
361-380	E (369)	90	D (365) L (377)	90	M (363)	80		90				85														
381-400	L (387)	85		80		85	E (386)	90				90														
401-420		95		80		90						90														
421-440		85		80																						

period is shown by the percentage of correct responses made by each fish in each 20 trials. As in Experiment I, the number of errors, even at the beginning of the training, was small. In this experiment the daily procedure was to give only as many trials as were required for making 3 or 4 correct responses, as described under the previous discussion of method. The learning would undoubtedly have been faster if, in addition to the rewarding of correct responses, some form of punishment had been given in connection with the incorrect choices. The number of errors in the first of the daily trials is slightly larger than the number of errors in the later trials of the day for 8 of the 13 fishes. This difference may be explained by the fact that the transfer from the living-tank to the discrimination apparatus caused some slight disturbance which would affect the behavior in the first trials but would wear off as the fish remained longer in the discrimination box. A comparison of the distribution of errors throughout the daily trials of the group having trials in quick succession and the group having an interval of seven minutes between each two trials shows that for the latter the errors are more evenly distributed throughout the 3 or 4 trials of each day. In this case the disturbance caused by the transfer from the tank to the experimental apparatus was approximately equal for each trial. There was no opportunity for the adaptation to the new conditions that was apparent in the other group. The fishes that were experimented on first in the daily testing showed no more errors than those that were tested later in the group. There ap-

peared to be no accumulation of traces of food to act as cues in the later trials.

The distribution of errors according to the right-left position of the positive stimulus is shown in Table 12. In two cases (fishes No. 2 and No. 8) the number of errors when the positive stimulus was on the right was considerably larger than the number of errors when the positive stimulus was on the left. In two cases (fishes No. 9 and No. 10) the reverse was true. The records of the other 9 fishes show no evidence of preference for either position of the stimulus.

The number of trials required to establish discrimination with each of the stimulus sets used is given in Table 13. In those cases where training with a particular stimulus pair was repeated after training with some other pair the results of the separate training periods are given. Twelve of the 13 fishes learned to discriminate the two circles differing by 2 cm. in diameter. One failed to make 24 out of 25 correct responses to this stimulus difference during 197 trials. The number of trials before learning the easiest discrimination varied from 50 to 127 trials. The average for all the fishes was 79 trials, representing approximately 19 days' training. The fishes trained to the larger stimulus learned the discrimination in fewer trials (average, 63.8; range, 50-99) than those learning to go to the smaller circle (average, 91; range, 55-127). In two cases the number of trials for learning to go to the larger stimulus was greater than the average for the group learning to go to the smaller circle; in five cases it was less. In five cases the num-

TABLE 12

SHOWING THE NUMBER OF ERRORS FOR RIGHT AND LEFT POSITIONS OF THE POSITIVE STIMULUS

		Fish No. 1		No. 2		No. 3		No. 4		No. 5		No. 6		No. 7		No. 8		No. 9		No. 10		No. 11		No. 12		No. 13	
Trials	Positive stimulus	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors	Correct responses	Errors
1-100	Right	27	22	33	18	33	20	35	13	27	21	32	15	41	10	35	18	37	13	45	6	43	7	35	9	47	5
	Left	35	18	32	17	30	17	43	9	31	21	37	16	35	14	40	7	35	15	33	16	43	7	41	15	42	6
101-200	Right	43	7	40	9	39	10	47	3	45	3	46	5	44	8	44	8	49	4	47	3	43	6	44	11	37	4
	Left	45	4	50	1	44	8	46	4	45	4	47	2	41	7	44	4	40	7	47	3	46	5	35	7	47	4
201-300	Right	49	4	40	8	49	4	48	4	45	3	48	4	46	4	50	6	33	1	32	3	35	4				
	Left	44	3	47	5	42	5	41	8	44	4	41	7	42	7	39	5	41	6	50	8	37	4				
301-400	Right	64	6	71	17	50	3	47	7	10	4	48	2	10	3	12	5										
	Left	51	12	46	6	47	9	41	4	13	1	43	5	11	1	16	1										
Total	Right	183	39	184	52	170	37	177	27	131	31	174	32	141	26	141	17	124	18	124	12	121	17	79	20	64	9
	Left	174	37	175	29	163	39	171	24	136	30	168	30	129	29	139	17	116	28	130	27	126	16	76	22	89	10

TABLE 13

Showing the Number of Trials Required to Establish Discrimination with Each Stimulus Set Used in the Training Series

The differences in diameters of circles are expressed in centimeters. *F* indicates failure to learn in the number of trials given.

Difference in diameters of circles	No. tested	Fish No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11	No. 12	No. 13
2.0	15	104	84	95	55	127	81	67	51	99	53	63	F197	50
1.0	12	22	50	58	23	0	28	18	20	0	33	6		13
				59										
0.5	12	7	0	0	0	15	0	62	28	81	8	0		20
0.3	9	10	34		18	27	0	16	2	10	13			
		1	0		5		0							
0.2	8	F24	17	F35	F33	F54	F58	F48	F57					
		F51	F23	35	F55									
		F 8			F43									
					F14									

ber of trials required for learning to go to the smaller circle was greater than the average for the group learning to go to the larger circle; in one case it was less.

A comparison of the results of the fishes that were given trials in immediate succession with those that were allowed an interval between trials shows some difference in speed of learning. The latter group learned the easiest discrimination in fewer trials, the average number of trials being 71.5 as compared with 83.3 trials for those having intervals between tests. Only one of the group having intervals required more trials than the average number taken by the other group, whereas five required fewer trials. Four of the group trained in successive trials required more trials than the average number taken by the group having intervals between trials; two required fewer trials.

There was considerable irregularity in the effect on discrimination of changing the stimulus pairs. In 10 out of 12 cases the change from a difference of 2 cm. in the diameters of the circles to a difference of 1 cm. caused errors to be made. In 7 cases out of 12 the change from a difference of 1 cm. to a difference of 0.5 cm. in the diameters of the circles caused errors. In none of these instances was the number of trials necessary to establish perfect discrimination with these stimulus sets as great as it had been for the original stimulus pairs. When the stimulus difference was reduced to 0.3 cm., errors in discrimination were made by 8 of the 9 fishes tested. All these fishes learned the discrimination after further training, the number of trials

required ranging from 2 to 27. There was a general breaking-down of the discrimination habit when the difference in diameters of circles was reduced to 0.2 cm. There were two exceptions to this. One fish (No. 2) made 12 successive correct choices after 17 trials, but later failed with this discrimination in 23 tests. One fish (No. 3) failed in 35 trials, but, after being tested again with a stimulus pair of greater difference, discriminated perfectly between the circles differing by 0.2 cm. in diameter when further training was given. Repeated testing with the other 6 fishes failed to show any evidence of learning to discriminate this difference in the size of the two stimuli.

When the discrimination of stimuli differing 0.5 cm. in diameter had been learned, a series of control tests was made. The stimulus sets used in these tests are given in Table 14. The position of both lights was changed

TABLE 14

SHOWING THE STIMULUS SETS USED IN THE CONTROL TESTS

The diameters of the circles in each set are expressed in centimeters. The distance of the lights from the stimulus plates is also indicated.

	Stimulus set				
	K	L	M	N	O
Positive stimulus	3.0	3.0	3.0	3.0	3.0
Negative stimulus	3.5	3.3	3.2	2.5	2.7
Distance of lights from stimulus plates	20	varied	varied	20	varied

from 10 cm. to 20 cm. from the stimulus plates, and further trials were given. Five fishes made no errors, or errors on only the first day of these tests. Six fishes required several trials before making perfect discrimina-

tion under these conditions. One fish failed in 49 trials. The number of trials required for learning with this change in the total quantity of light in the stimuli is given in Table 15. The appearance of disturbance under these conditions indicates that in learning to discriminate under the original conditions the response was determined to some extent by the absolute brightness or luminosity of the areas. If the discrimination had been based entirely on differences in the size of the stimuli, a change in the illumination would not have caused errors.

Control tests were introduced again after perfect discrimination between circles differing by 0.3 cm. in diameter had been learned when the lights were equally distant from the stimulus plates. The same stimulus sets were used, but the position of the lights was changed from trial to trial, as described earlier in this experiment. In this way both the absolute and the relative photic effects of the two areas were varied. In some tests the stimuli were of equal brightness, in others they differed as much as 1:14. The quantity of light in the smaller circle was made greater in half the presentations. This change in positions of the lights caused errors in all but one case. The number of trials required before making 12 successive correct responses under these conditions, when the choice had to be made on the basis of size alone, is given in Table 15. The 8 fish tested learned the discrimination. In two cases (No. 3 and No. 7) no errors were made when the quantity of light in the stimuli was varied in this manner. Two fishes (No. 2 and No. 6), after making 12 succes-

TABLE 15

SHOWING THE NUMBER OF TRIALS BEFORE PERFECT DISCRIMINATION IN THE CONTROL TESTS

The differences in diameters of circles are expressed in centimeters. *F* indicates failure to learn in the number of trials given.

Difference in diameters of circles	Distance of lights from stimulus plates	Fish No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11	No. 12	No. 13
0.5	20cm.	11	1	23	5	0	17	0	32	2	13	16	—	F49
0.5	varied	9	43	0	12	3	1	0	58					
		7	F64	5	6		F56							
		52			24									
0.2	varied			F47										

sive correct trials under these conditions, failed to discriminate perfectly in later trials, after intervening testing with a smaller stimulus difference.

Control tests of the same type were given to fish No. 3, using stimuli differing by 0.2 cm. in diameter after discrimination between the circles when the lights were equidistant had been established. In the 47 trials given, the percentages of correct choices per 10 trials were 90, 70, 90, 80, and 90. The fish did not succeed in making 12 successive correct responses during the training with this stimulus set when the quantity of light in the stimulus areas was varied.

Analysis of the results during these control experiments shows the prevalence of reactions based on the brightness of luminosity of the stimuli. If the fish had been trained to the smaller stimulus, when the position of the lights was varied it chose the dimmer area more often than the lighter area, regardless of its size. On the other hand, there was some evidence that training to the larger stimulus led to choice of the brighter of the two unequally lighted areas in the control tests, although the effect of the previous training was less evident in this case. Other tests on the goldfish have shown that there is an avoidance of very bright stimuli when a choice of differently illuminated areas is given (21). The results of these control tests are shown in Table 16. The number of errors made when the positive stimulus had the same relation to the negative stimulus as in the training series (i. e., darker or lighter), and the number of errors made when the relative brightness of the two stimuli was altered (i.e., if the positive stimulus was

TABLE 16

SHOWING PERCENTAGE OF RESPONSES TO DARKER AND TO LIGHTER STIMULUS WHEN BRIGHTNESS OF AREAS WAS VARIED

Fish	Positive stimulus in training series	Percentage of errors in control tests: Positive stimulus darker	Percentage of errors in control tests: Positive stimulus lighter
No. 1	darker	5.6	12.7
No. 2	darker	12.3	19.7
No. 3	darker	5.0	0
No. 4	darker	2.2	12.9
No. 5	darker	0	12.5
No. 6	darker	9.3	12.9
No. 7	lighter	9.0	0
No. 8	lighter	11.1	11.4

darker in the training series, it was lighter in these tests; and vice versa), is expressed as a percentage of the total number of presentations in which these combinations were used. In six of the eight cases fewer errors were made to a positive stimulus that retained the same relation to the negative stimulus that it had had in the training series than to this same positive stimulus when the brightness relations were reversed.

The average time for discrimination is shown in Table 17. The results are given for each 20 trials throughout the training. In the group learning to go to the smaller circle (fishes Nos. 1, 2, 3, 4, 5, and 6), there was an increase in time for choice in the second hundred trials. In four of the six cases there was a further increase in the third hundred trials. In the group learning to go to the larger circle (fishes Nos. 7, 8, 9, 10, 11, 12, and 13), in six of the seven cases the time decreased in the second hundred trials, and decreased still further as the training continued. As Table 13 shows, the average

TABLE 17

Showing the Average Time in Seconds for Choice for Each Fish per 20 Trials

The trial at which the stimulus set was introduced in the training series is indicated by the number in parenthesis

Trials	Stimulus set	Fish No. 1	Stimulus set	Fish No. 2	Stimulus set	Fish No. 3	Stimulus set	Fish No. 4	Stimulus set	Fish No. 5	Stimulus set	Fish No. 6	Stimulus set	Fish No. 7	Stimulus set	Fish No. 8	Stimulus set	Fish No. 9	Stimulus set	Fish No. 10	Stimulus set	Fish No. 11	Stimulus set	Fish No. 12	Stimulus set	Fish No. 13
1- 20	A	7.9	A	9.6	A	31.5	A	13.0	A	5.3	A	5.6	F	85.8	F	19.1	F	13.6	F	51.4	F	21.0	F	52.1	F	51.8
21- 40		7.7		6.8		61.2		10.0		3.8		15.9		101.7		24.4		13.7		28.6		22.9		27.6		35.6
41- 60		5.9		5.6		37.7		24.3		9.1		6.3		115.1		49.4		22.7		25.0		29.5		46.4		36.0
61- 80		7.5		5.4		27.0		21.2		6.8		14.3		92.4	G (80)	88.6		26.0		19.1		54.2		55.3		60.9
81-100		15.3		8.8		64.3	B (82)	24.9		7.0		25.5	G (96)	58.4		43.2		19.5		23.4	G (91)	50.5		37.4	G (83)	50.4
101-120		16.0	B (112)	16.0		80.1	C (120)	22.4		11.6	B (107)	36.1		63.1	H (113)	42.0		20.7		21.2		45.8		36.8	H (109)	28.8
121-140	B (131)	16.5		10.1	B (123)	100.5	K (132)	26.5		20.3		25.9	H (126)	79.3		48.3	G (128)	23.2	G (123)	15.9		58.0		45.5		46.4
141-160		20.4	C (157)	14.2		132.2	D (149)	28.5	B (157)	7.6	C (148)	39.0		34.1	N (154)	43.6	H (141)	18.0		13.4		63.0		33.1	N (144)	33.1
161-180	C (168)	23.5	K (169)	15.9		104.6	L (180)	23.6	C (169)	8.8	K (161)	24.6		43.2		42.6		14.1	H (176)	26.2		44.6		32.4		31.2
181-200	K (190)	24.4	D (186)	9.6	C (195)	80.2		25.4		11.7	D (191)	33.9		36.7	I (200)	33.9		7.8		13.0		46.4		25.5		34.7
201-220	D (216)	31.3		10.6	K (207)	77.9		28.2	K (219)	8.3	L (202)	32.3	N (202) I (214)	39.8	O (216)	39.2		16.6	N (203)	9.7	H (213)	27.1				
221-240	L (239)	31.9	L (233)	10.9		47.5	E (223)	24.8	D (231)	6.6		41.5		29.5		46.5	N (235)	9.4	I (230)	12.1	N (225)	19.2				
241-260		35.3		15.4	L (242) E (256)	45.0	L (256)	23.2		8.7		37.3	O (243)	49.8		31.4		13.5		10.5		24.7				
261-280	E (263)	58.3		9.5		44.9	E (265)	27.6	L (270)	7.9		35.6	J (262)	31.9		36.5	I (264)	13.2		10.3		18.8				
281-300	L (297)	42.9		36.8	L (291)	32.3		29.9	E (286)	12.1	E (283)	37.5		37.4	J (287)	19.4				13.2						
301-320	E (305)	33.2	E (315)	21.7	E (311)	39.8	E	21.8	E	20.0	E	39.5	I (320)	30.3	J	25.2										
321-340		30.6		29.4		52.7	D (330)	20.7		10.1	D (337)	26.5		21.1		26.7										
341-360	D (357)	39.0		25.8		40.2	L (349)	14.9			L (349)	21.6														
361-380	E (369)	33.7	D (365) L (377)	32.3	M (363)	29.4		16.5				17.6														
381-400	L (387)	35.9		18.3		29.1	E (386)	14.9				15.2														
401-420		16.0		23.6		33.0						23.7														
421-440		22.6		21.3																						

number of trials for learning the easiest discrimination was less for this group than for those trained to the smaller circle. The time for the total response decreased with training in 10 of the 13 cases. The average time for the total response during the first 100 trials was approximately 92 seconds; for the remaining trials, 60 seconds. In nearly half the instances in which a new and more difficult stimulus pair was introduced in the training, the time for discrimination increased in the trials immediately following the change in stimuli.

The difference in time required for discrimination in Experiments I and II may be accounted for by the differences in the apparatus. In Experiment I the slowness of the early reactions was doubtless due to the disturbance caused by the transfer into the experimental apparatus, where the lighting, shadows, and surroundings were unlike those of the living-tank. When the fish became used to these conditions, or to being moved from living-tank to discrimination box, there was a marked drop in the time preliminary to the choice reaction. In Experiment II, with uniform environment and lighting in the tank and in the discrimination apparatus, there was little disturbance of this kind, so that "discrimination" time did not decrease as much during the course of training. Here, however, the larger dimensions of the apparatus allowed more room for swimming back and forth before making a choice, and consequently the time for discrimination tended to be higher.

A comparison of the results of the group having trials in immediate succession with those having longer inter-

vals between trials shows that the time for choice was longer for the former group (average of 36 seconds, as compared with an average of 28 seconds). The time for total reaction was also longer for this group (average, 81 seconds, as compared with 51 seconds). The factor of motivation doubtless entered in here. When the fish was given three or four pellets of food as quickly as it made that number of correct choices the hunger drive would naturally be less effective as an incentive to response in the later trials. When the fish was returned to the living-tank each time that it secured a bit of food, it ate the food during the interval before it was returned to the apparatus and was ready for another pellet by the time of its next trial. The responses, in this case, would tend to be made more quickly.

Table 18 shows the average time taken for correct choices and for errors. In 8 of the 13 cases the time for correct choices was greater; in 4 cases the time for correct choices and for errors was approximately the same; and in 1 case the time for correct choices was shorter. The differences are, however, not statistically reliable. In the case of fish No. 11, there are 90 chances in 100 that the difference represents a true difference. The differences in the other records are less significant. These results differ from the findings in Experiment I. In the previous experiment the errors were made after more or less time had been spent in random swimming about the tank, whereas the correct choices were made quickly when the fish attended to the stimulus pair. In Experiment II there was noticeably less of the random swimming. As soon as door D^1 was opened, the fish

TABLE 18

SHOWING THE AVERAGE TIME IN SECONDS FOR CHOICE FOR EACH FISH PER 100 TRIALS AND THE AVERAGE TIME FOR ALL RESPONSES, FOR CORRECT RESPONSES, AND FOR ERRORS

	Fish												
Trials	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11	No. 12	No. 13
1-100	8.7	7.2	44.2	18.6	6.4	13.7	97.2	44.5	19.1	30.1	35.6	43.8	47.1
101-200	20.1	13.1	99.6	25.3	12.2	31.9	56.0	42.1	16.7	17.9	51.5	34.8	34.5
201-300	39.9	16.6	49.5	26.7	8.7	36.7	43.7	34.6	13.6	11.3	22.5		
301-400	54.6	25.4	38.2	18.7	17.2	24.2	28.5	25.7					
401-440	18.6	22.4	33.0			22.2							
Total, av.	25.4	16.3	57.4	22.4	9.8	26.6	61.4	38.9	16.7	20.0	37.6	39.4	41.1
Correct, av.	27.2	17.2	58.2	23.6	9.9	27.6	60.3	40.6	16.7	20.1	39.1	39.3	42.3
Errors, av.	16.5	12.2	53.9	20.9	9.6	21.3	66.7	30.8	16.6	19.3	26.2	39.9	30.4

moved into compartment B, and from there, with little delay, into one of the passages at the side of the partition. The tendency was to make quicker choices when the difference between the stimuli was great and to hesitate longer over the more difficult discriminations.

The number of responses showing marked hesitation before choice was relatively greater in this experiment than in the previous one. On the average, this hesitation delayed the response 5 seconds. In all cases more of the responses made after hesitation were correct than were incorrect. More correct choices were made after hesitation than were made without hesitation. Table 19 shows the proportion of correct and incorrect discriminations made with hesitation before choice.

The results of the experiment show that the goldfish can discriminate between two visual stimuli on the basis of the difference in the size of the areas. When the lights illuminating the stimulus plates were at the same distance from the two stimuli, all the fishes discriminated between circles differing in diameter by 2 cm., 1 cm., 0.5 cm., and 0.3 cm. Two fishes discriminated between circles differing in diameter by 0.2 cm. When the absolute and relative photic effects of the two areas were varied from trial to trial, 6 fishes discriminated between a standard circle 3 cm. in diameter and a circle 0.3 cm. larger. Two fishes discriminated between the standard circle of 3-cm. diameter and a circle 0.3 cm. smaller. In one case, a circle differing by 0.2 cm. from the standard was successfully discriminated when the amount of light in the two areas was varied from trial to trial. Compared with limens for visual discrimina-

TABLE 19

SHOWING THE PERCENTAGE OF CORRECT AND INCORRECT CHOICES AFTER HESITATION

	Fish												
	No. 1	No. 2	No. 3	No. 4	No. 5	No. 6	No. 7	No. 8	No. 9	No. 10	No. 11	No. 12	No. 13
Total trials	433	440	409	399	328	404	325	334	286	293	280	197	192
% of trials showing hesitation	35	18	34	39	11	21	25	33	12	9	19	7	15
% incorrect after hesitation	6	2	10	5	0	2	12	9	0	0	3	13	6
% incorrect without hesitation	23	21	22	17	21	18	18	19	18	14	13	21	10

tion in other animals, these results show a high degree of acuity in the goldfish. Bingham (1) found the limen for the chick to be a circle from 1/4 to 1/6 larger than the standard circle of 6-cm. diameter. Coburn's (6) experiments showed that crows could distinguish between circles when the difference in diameters was 1:10 although no attempt was made to determine whether this was the threshold for discrimination. The limen for discrimination of size in goldfish, under the conditions of the present experiment, is a difference of 1/10 of the diameter of the standard circle of 3.0-cm. diameter.

IV

SUMMARY AND CONCLUSIONS

A. *Pattern Discrimination.* Six goldfish, *Carassius auratus*, were trained to discriminate visual stimuli of different patterns. The stimuli consisted of cards on which were painted black and white stripes of equal widths. The following results were obtained:

1. All the fishes learned to discriminate between cards having stripes 10 mm. wide and cards having stripes 2 mm. wide.

2. Four fishes discriminated between the patterns when the stripes on the two fields were 10 mm. and 5 mm., respectively.

3. One fish consistently chose the card bearing the narrower stripes when the difference in width of stripes was 2 mm.

B. *Size Discrimination.* Thirteen goldfish were trained to discriminate visual stimuli of different sizes. The stimuli consisted of illuminated circles of unequal areas, the standard stimulus being a circle 3 cm. in diameter. The following results were obtained:

1. Twelve fishes learned to discriminate between circles differing in diameter by 2 cm., 1 cm., and 0.5 cm. when the brightness of the areas was not equated. Nine fishes learned to discriminate circles differing by 0.3 cm. under the same conditions. Two fishes learned to go to the smaller circle when the difference in diameter of the two circles was 0.2 cm.

2. When the absolute and relative photic effects of the stimulus areas were varied from trial to trial, 8 fishes discriminated perfectly between circles differing by 0.3 cm. in diameter. Only one fish learned this discrimination when the difference in diameters of the two circles was 0.2 cm. Under these conditions the limen for discrimination of size is 1/10 of the standard circle of 3 cm. diameter.

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LES SEUILS DE DISCRIMINATION DE FORME ET DE GRANDEUR CHEZ LE POISSON ROUGE *CARASSIUS AURATUS*

(Résumé)

On a fait deux expériences pour déterminer les plus petites différences que le poisson rouge *Carassius auratus*, peut distinguer dans (1) des stimuli visuels de différentes formes; (2) dans des stimuli visuels de différentes grandeurs. On a employé une boîte modifiée Yerkes-Watson, les réponses correctes étant récompensées par de la nourriture. Dans l'expérience 1 les stimuli ont consisté en cartes sur lesquelles ont été peintes des bandes noires et blanches de même grandeur. Six poissons ont appris à discriminer entre les formes quand les bandes sur les deux champs ont été grandes de 10 mm. et de 2 mm. respectivement. Quatre de ces poissons ont parfaitement discriminé quand les bandes ont été grandes de 10 mm. et de 5 mm. De plus petites différences de forme ont été discriminées par un poisson. Dans l'expérience 2 les stimuli ont consisté en aires illuminées de grandeur inégale, le stimulus étalon étant un cercle d'un diamètre de 3 cm. Douze poissons ont appris à discriminer entre le cercle étalon et les stimuli qui ont un diamètre différent de 2 cm., de 1 cm., et de 0,5 cm. quand la clarté des aires n'a pas été rendu égale. La discrimination entre des cercles différant de 0,3 cm. a été faite par neuf poissons; et de cercles différant de 0,2 cm. par deux poissons. Quand les effets photiques absolus et relatifs des aires des stimuli ont été variés d'épreuve en épreuve (au moyen de changer la distance des lumières des plaques stimulantes), huit poissons ont parfaitement discriminé entre des cercles différant de 0,3 cm. en diamètre. Un poisson a discriminé quand la différence a été réduite à 0,2 cm. Dans ces conditions le seuil pour la discrimination de la grandeur a été le dixième du cercle étalon.

ROWLEY

DIE UNTERSCHEIDUNGSFÄHIGKEIT DES GOLDFISHES (*CARASSIUS AURATUS*) IN BEZUG AUF GESTALT UND GRÖSSE

(Referat)

Es wurden zwei Versuche unternommen, zur Bestimmung der kleinsten Unterschiede, die von dem Goldfisch, *Carassius auratus*, vernommen werden konnten: (1) bei visuellen Reizungen durch verschiedene Gestalten, und (2) bei visuellen Reizungen durch verschiedene Grössen. Es wurde der Yerkes-Watson'sche Versuchskasten verwendet; richtige Reaktionen wurden mit Essen vergeltet. Im ersten Versuch bestanden die Reize aus Karten, welche mit schwarzen und weissen Streifen von gleicher Breite bemalt waren. Sechs Fischen gelang es, zwischen den Mustern [patterns] zu unterscheiden, wenn die Streifen auf den zwei Feldern respektiv 10 mm. und 2 mm. breit waren. Vier dieser Fische machten durchaus richtige Unterscheidungen wenn die Streifen auf den zwei Feldern respektiv 10 mm. und 5 mm. breit waren. Einem Fisch gelangen sogar feinere Unterscheidungen zwischen verschiedenen Streifbreiten. Im zweiten Experiment bestanden die Reize aus erhellten Flächen ungleicher Grösse, wobei ein Kreis mit einem Durchmesser von 3 cm. als Normalreiz galt. Zwölf Fische lernten, zwischen dem Normalkreis und Reizen zu unterscheiden, deren Durchschnitt 2 cm., 1 cm., und .5 cm. von dem Normaldurchschnitt abwichen, ohne Gleichschaltung der Helligkeit der Flächen. Neun Fischen gelang es, zwischen Kreisen, deren Durchmesser .3 cm. von einander abwichen zu unterscheiden, und zwei Fischen gelang die Unterscheidung bei .2 cm. Unterschied. Variirte man die absoluten und relativen Lichteinwirkungen [photic effects] der Reizflächen in den verschiedenen Versuchen dadurch, dass man die Entfernung der Lichter von den Reizplatten wechselte, so unterschieden acht Fische durchaus richtig zwischen Kreisen, deren Durchschnitte .3 cm. von einander abwichen. Ein Fisch konnte noch unterscheiden, wenn der Unterschied bis auf .2 cm. herabgesetzt worden war. Unter diesen Umständen betrug die Unterscheidungsschwelle [limen for discrimination] für Grösse ein Zehntel des Normalkreises.

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From the Animal Laboratory of the Department of Psychology, Columbia University

By

BERNARD F. RIESS

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I

INTRODUCTION

During the past few decades a wide variety of apparatus has been devised for use in the study of the reactive capacities of animals. In spite of this fact, the various devices in use may be classified into two general types: (1) mazes and (2) problem apparatus. Some notion of the great variety of maze patterns that have been developed may be had by referring to the recent monograph of Warner and Warden (17). A less-detailed classification of types of problem boxes will be found in an article by Jenkins (6). As these authors point out, mazes and problem boxes have usually been devised with reference to a particular species of animal and are seldom generalized enough to be useful in the comparison of animals of different species. They have been used, in most cases, to study various conditions of learning within a given species. It should be clear that any comparative psychology worthy of the name must include the intercomparison of species, genera, phyla, and the like. This involves the testing of different types of organism on the same task under properly standardized conditions. The interest in strictly comparative problems was the first to arise in the animal field. The need for this type of study has been emphasized by Thorndike, Yerkes, Watson, and many other leaders. In spite of this fact, this phase of the program of comparative psychology has been largely neglected. *The reason for this neglect is not far to* seek. It is extremely difficult to arrange a standard

task for species of animals which differ in motor equipment. Pulling a string may be easy for a cat or monkey but it is likely to be difficult for a dog or a guinea pig. If such a device were used, differences in score would reflect differences in intelligence much less, perhaps, than divergence in the type of appendage possessed by the several species. It may be laid down as a general principle that any common task to be used in comparative tests must require some type of manipulation that is natural to each of the species to be tested. The task may be complicated by introducing spatial and temporal pattern factors rather than by bringing in a new type of movement which is less natural to some species than to others.

The Jenkins problem box, which will be described in the following chapter, was especially devised for the comparative study of mammalian types. The motor response itself involves merely the stepping on a plate in the floor of the apparatus—a movement that is simple and natural for all types of mammal. The task is complicated by introducing a progressive series of pattern elements—all of the same general order on the motor side. Since it is possible to complicate the task within extremely wide limits, it is possible to determine the levels of capacity of various species for this kind of task. The apparatus is being utilized in the Columbia Laboratory to determine comparative indices on various mammalian forms. The limits of learning in kittens as determined by this method have already been reported by Shuey (13). The present monograph is devoted to a comparison of two common rodents: the white rat and the guinea pig. The work

on the rhesus monkey by Fjeld will appear in a later monograph in this series, while the testing of the cebus monkey is now under way in this laboratory.

Historical background for the present series of experiments is almost wholly lacking. The nearly complete lack of information on learning in the guinea pig is all the more noticeable in view of the extensive literature concerning itself with the white rat. But five studies have been made which cover modification of behavior in the guinea pig. Of these, two deal with the problem box. Muenzinger (10) and Muenzinger, Koerner, and Irey (11) have investigated mechanization and plasticity of behavior in a simple thumb-latch box. The other studies are a simple discrimination transfer problem undertaken by Hadley (4), an application of the conditioned-response technique to auditory limens by Upton (14), and a duplication of Watson's early rat work by Allen (1). The latter study *represents the sole attempt to compare these two common rodents.* Allen's results on nervous development as correlated with behavior are compared to identical work done by Watson on the white rat. However, the situations studied were extremely simple and the technique poorly standardized.

Limits of learning as a problem in comparative psychology has an even more incomplete past. No experimentation has been conducted on the problem in rodents and there are few studies of the higher orders. The present experiments, together with those in progress at the Columbia Laboratory, may be considered as attempts to fill out this gap in comparative learning studies of mammalian types.

II

APPARATUS

Description of Apparatus. The apparatus used in these experiments is a modification of the problem box described by Jenkins (6) and employed by Shuey (13) on kittens. The external appearance and dimensions of the box are shown in Figure 1. The floor consisted of a solid piece of smooth, white pine mounted on legs

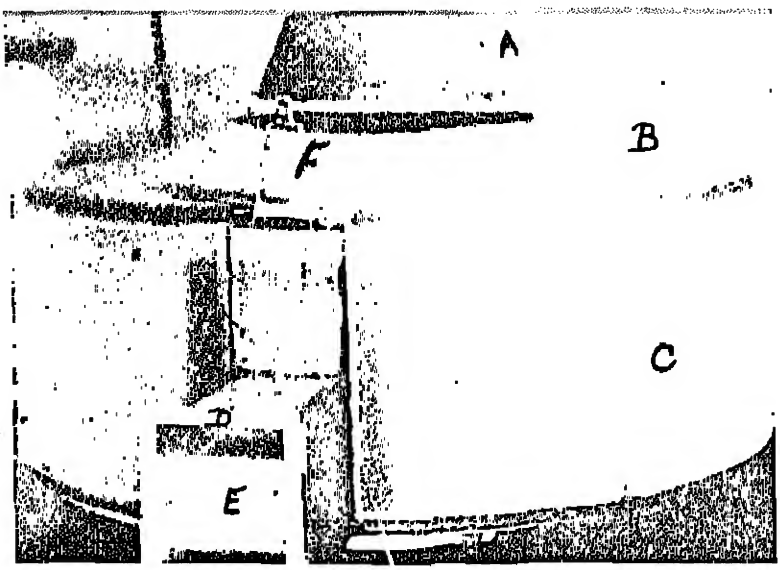

FIGURE 1

Exterior of Problem Box

A—light source, 45 cm. in diameter; height above cage, 5 cm.
B—cover of reaction compartment, height from top of compartment at inner edge, 14 cm.; distance from edge to edge, 45 cm.
C—one-way light screen, height from floor of box, 45 cm.
D—entrance box, 23 x 24 x 36 cm.
E—door to entrance box
F—pulley and cord connecting door with control table

which raised it to a height of 45 cm. from the floor of the room. The problem box itself was constituted of three cages (Figure 2): an entrance box, the reac-

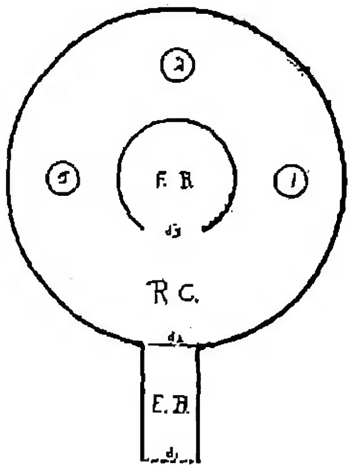

FIGURE 2

DIAGRAM OF THE FLOOR PLAN

E.B.—entrance box
R.C.—reaction compartment
F.B.—food box
1, 2, 3—plates, 15 cm. in diameter
d_1, d_2, d_3—doors to the entrance box, reaction compartment, and food box

tion compartment, and the food box. The entrance box floor was of wood with metal sides and 1-inch heavy wire-mesh top. It was screwed to the test cage in such a way that its floor was flush with that of the reaction compartment. Doors closed off both ends; that which led to the test cage was made of mathematical celluloid and was operated noiselessly in oiled

grooves. It was raised by a cord passing over a pulley and fastened at the other end to the control table.

The reaction compartment and the food cage were concentric cylinders of 1-inch heavy wire mesh. The distance from the outer wall to that of the incentive box was 45 cm. In the latter, opposite and parallel to the door of the reaction cage, was a curved, wire-mesh door (Figure 2) which moved in an arc parallel to the circumference of the food box. Broken lines mark its open position (Figure 2).

In the floor of the test cage were three circular plates (Figure 2) of hard maple into which had been sunk thin copper strips so connected to a Columbia Electric Stimulator that an animal could be given a shock if desired. The plates were level with the floor and remained in natural color whereas the floor itself was painted battleship gray.

The reaction compartment was entirely surrounded with a one-way light screen of fine copper mesh sprayed with white paint. Four removable circular segments made of the same screening served as covers for the cage. These sloped upwards toward the light source. This consisted of a circular reflector hung on a swinging arm bracketed to the wall of the room. Light was diffused equally over the entire box by eight 40-watt Mazda lamps arranged in a circle back of a ¼-inch opal glass plate. In order to make the one-way screen effective, the experiment was conducted in a dark-room.

The control table, at the end of which the experimenter sat, was 80 centimeters to the right of the prob-

lem box. Two tall wooden screens, painted white, served to make the background to the right and in back of the box similar to that of the rest of the room. The mechanism of control is given in Figure 3. The elec-

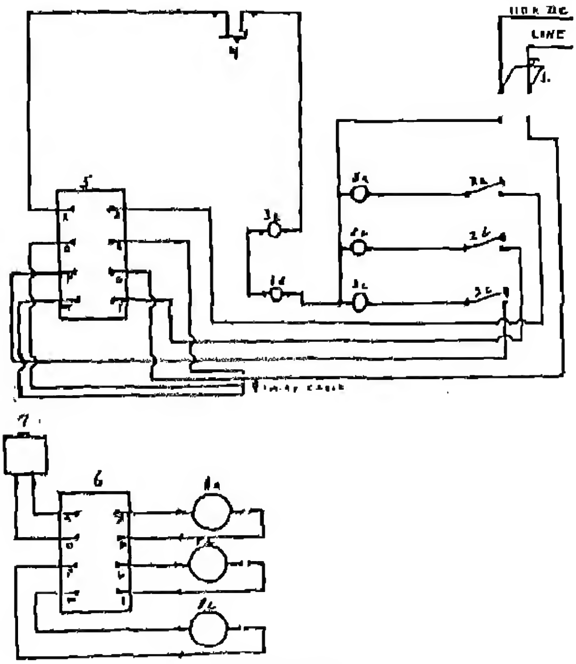

FIGURE 3

DIAGRAM OF ELECTRICAL APPARATUS FOR THE RELEASE OF THE DOOR

1—switch controlling input
2a, 2b, 2c—switches controlling signal lights
3a, 3b, 3c—signal lamps
3d, 3e—resistance lamps
4—telegraph key
5—bakelite, multi-contact, panel plug
6—bakelite, multi-contact, panel socket in box
7—electromagnet
8a, 8b, 8c—connections to three plates
Numbers 1 to 5 are related to the control table, numbers 6 to 8 are found on the box itself.

III

ANIMALS AND PROCEDURE

Animals

The subjects in the first part of the study, hereinafter called Experiment I, were 35 albino rats supplied by the Albino Supply, Inc., Philadelphia, Pennsylvania. Age-weight data for the individual animals are given in Table 1. All rats were males of medium size, weighing from 80 to 100 grams, with an average weight of 87.7 grams. The last item recorded for each animal in Table 1 represents the age at which the rat was finally discarded after having failed to attain the norm of mastery set for the problem.

In Experiment II the subjects were 30 varicolored guinea pigs obtained from the Breeding and Laboratory Institute, New York City. Table 2 shows the age-weight data for the individual guinea pigs. The animals were males of medium size, averaging 387.9 grams in weight with a range of 380 to 402 grams.

A comparison of two types of animals under identical conditions involves the equation of the two groups in age, sex, and other factors at the outset of experimentation. Inasmuch as rats and guinea pigs vary widely in the degree of development at birth and in the rate of postnatal growth, it is difficult to determine the ages at which these animals arrive at exactly the same level of maturity. Figure 5 shows the data relevant to the question. The curve for rats was obtained from Donaldson (2), that for the guinea pigs from Minot (9).

The age and weight at sexual maturity are indicated

TABLE 1

Showing Weight (in Grams) and Age (in Days) at the Beginning and the End of Experiment I

The age records are obtained by adding to the number of days spent in the laboratory a constant, 60, which represents according to Donaldson (2, table 157, pp. 276 ff.) the age at weight 80-100 grams.

Rat number	Weight Beginning	Weight End	Age at end of Step I	Age at end of Step II	Age at end of Step III
1	80	176	158	298	
2	83	158	218		
3	80	171	109	219	
4	92	188	108	194	334
5	100	193	98	130	270
6	80	236	168	258	398
7	81	160	116	256	
8	95	111	135	275	
9	86	126	94	234	
10	84	120	218		
11	98	200	110	250	
12	91	190	218		
13	85	192	166	306	
14	83	162	218		
15	89	172	102	242	
16	94	164	138	278	
17	93	141	111	180	320
18	86	103	218		
19	97	134	218		
20	82	156	87	163	303
21	82	165	147	287	
22	91	186	124	264	
23	85	171	218		
24	80	190	106	246	
25	96	168	218		
26	90	212	148	288	
27	95	143	142	174	314
28	81	155	84	152	292
29	88	216	218		
30	93	187	134	184	324
31	91	176	118	258	
32	82	123	218		
33	80	117	218		
34	98	155	116	256	
35	81	138	118	258	

TABLE 2

SHOWING WEIGHT (IN GRAMS) AND AGE (IN DAYS) AT THE BEGINNING AND THE END OF EXPERIMENT II

The age records are obtained by adding to the number of days spent in the laboratory a constant, 73, which represents according to Minot (9, pp. 97 ff.) the age at weight 380-400 grams.

Guinea pig number	Weight Beginning	End	Age at end of Step I	Step II
1	380	524	124	244
2	385	541	226	
3	381	590	226	
4	392	467	226	
5	396	562	147	287
6	387	609	125	265
7	391	495	226	
8	393	677	181	301
9	385	589	132	272
10	389	571	122	262
11	394	601	226	
12	397	587	226	
13	387	524	226	
14	380	555	121	228
15	398	623	226	
16	402	672	150	290
17	379	486	137	157
18	386	533	116	216
19	388	506	226	
20	392	557	116	256
21	396	498	226	
22	384	625	111	251
23	381	501	226	
24	382	540	124	164
25	390	682	136	255
26	388	463	226	
27	381	784	180	320
28	385	497	226	
29	382	503	226	
30	386	692	174	314

for both groups in relation to the weight and age selected for experimentation. It will be seen that the animals used in both experiments were approximately at the same point of development in respect to the rate of growth and the date of sexual maturity. In order

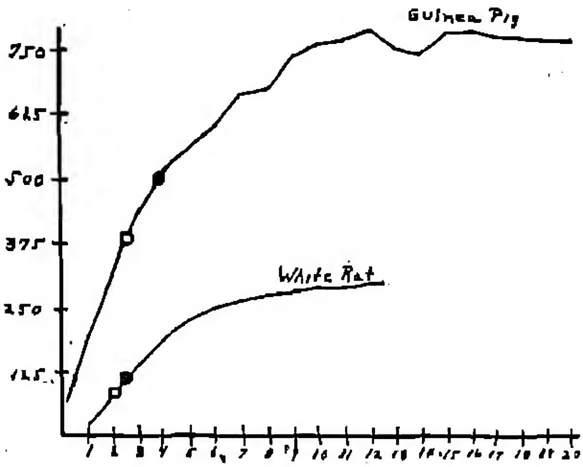

FIGURE 5

SHOWING THE WEIGHT IN GRAMS AT VARIOUS AGES IN MONTHS FOR WHITE RATS (MODIFIED FROM H. H. DONALDSON) AND FOR GUINEA PIGS

The ordinate axis represents weight and the abscissa age in months. Open circles indicate weight and age at time of arrival in the laboratory. Closed circles indicate the age and weight at sexual maturity.

to avoid any disturbance due to the oestrous cycle, only males were used in this experiment.

The preliminary procedure was devoted mainly to taming the animals and accustoming them to laboratory and experimental routine. Immediately after arrival in the laboratory, the animals were placed in the quarters in which they were to live throughout the experiment. The living-cages for the rats contained six animals each and were constructed of metal, 18 by 12 by 12 inches in size. They were closed on three sides and had a solid bottom on which sawdust was spread for bedding. Fresh water was obtainable

at all times from an inverted siphon bottle attached to each cage. The living-quarters for the guinea pigs also held six animals each but were much larger than those for the rat, being 24 by 22 by 30 inches in size. They were made of metal mesh and had heavy grills for floors, below which were removable metal pans full of wood shavings. Water jars were kept in all cages throughout the experiment. The task of motivating the animals was started on the second day of their laboratory life when they were fed at the hour at which food was to be given during the training period. The food itself was not administered in the living-cage but in identical cages which were, however, not supplied with sawdust. The white rats were given whole-wheat bread soaked in milk together with a bi-weekly ration of greens. The guinea pigs were fed chopped carrots and lettuce. Food for the rats was supplied in liberal amounts, about 6 ounces to a cage, and was removed after ten minutes, whereas the guinea pigs were allowed a limited amount of food which remained in the cage for two hours. The total weight of carrots and lettuce was 9 to 10 ounces to each group of six animals. The guinea pigs were fed for a longer period than the rats because it has been found that the former animals will not learn to gorge themselves in a limited time but nibble at the food intermittently over a longer interval. It was also found necessary to place large pieces of soft wood in the cages of the guinea pigs in order to satisfy the gnawing propensities of these animals.

On the third day, the ears of the animals were

clipped in various ways so as to differentiate one from another. All of the subjects were handled twice each day by the experimenter so as to accustom them to the removal to the experimental room, at a distance of some 70 feet from the vivarium. The treatment during this adjustment period was determined by preliminary investigation on separate groups of subjects. From the results of this survey it was decided to extend the handling of the guinea pigs one week beyond the fourteen-day period commonly adopted for white rats. The extension was made necessary because the guinea pigs did not respond to taming as readily as did the rats. The length of time adopted for each group was found to equate this difference in wildness very successfully.

A short period for adjustment to the apparatus has been found to be of value in much of the work in animal psychology. Warden (17) has shown that feeding and exploration preliminary to actual experimentation reduces the total learning time by more than 60 per cent. Therefore, following the laboratory adjustment interval, the animals were transferred, one at a time, to the apparatus which had been baited with food in the entrance and food boxes. Five minutes each in the two compartments was allowed the subject for exploration and the setting-up of food-association habits. The rats were given seven days of this treatment, the period for the guinea pigs being prolonged to twelve days. The difference, determined as above by preliminary experimentation, was caused by the persistence of non-adaptive behavior in the guinea pigs. All in all, then,

there elapsed three weeks from time of arrival to the beginning of testing for the rats and thirty-three days for the guinea pigs. In general, the variation in these periods may be ascribed to the slowness of adaptation in the latter group of animals.

Training Procedure

The first subject in the first cage was transferred to the entrance box. The experimenter then seated himself at the control table and pulled the cord which raised the door to the reaction compartment. As soon as the animal entered the latter, the stop-watch was started and various behavior records were taken. Immediately after the animal had stepped on the correct plate or plates, the telegraph key was depressed with the resultant release of the door from the electromagnet. The door opened and the animal was timed as it entered the food box. Each animal was allowed two to three nibbles of food and was then replaced in the entrance box. A time limit of five minutes per trial was set for the first 20 trials and thereafter at three minutes. If, at the end of that period, a subject had not made a correct response, it was placed in the entrance compartment and the trial listed as a failure. For the first six days of training, the above constituted the daily work per animal. On the seventh to the tenth days, the procedure was repeated twice and from the eleventh to the fifteenth, three times. Thereafter, the maximum number of trials was maintained at five per day for each animal. That this number did not result in a loss of motivation was brought out by comparison

of various distributions of practice among different preliminary groups.

When the subject had finished the daily task, he was returned to the food cage in the vivarium where he waited until all six animals in the living-cage had been run. Food was then placed in the food cage and the animals allowed to eat for ten minutes in the case of the rats and for two hours in the case of guinea pigs. The difference between the two types of rodents in feeding-times arose because it was found in preliminary experimentation that guinea pigs required a comparatively long time to finish the food set before them whereas rats learned to gorge themselves within the period allowed them. The incentives used in the problem box were whole-wheat bread soaked in milk for the animals in Experiment I and lettuce for those in Experiment II. Both the bread and lettuce were chopped into such minute pieces that no animal was able to retain any of the incentive after the time allowed for eating at the end of each trial. In addition to the available incentive, a dish of the same food was placed in the food box but was covered with a large inverted hemisphere of fine wire mesh. This prevented the animal from eating the contents of the dish, which acted as a stimulus enhancing the value of the original incentive. Throughout all trials the experimental room was kept in darkness. A large, high-speed, electric fan served as a constant noise screen and prevented any disturbances from street and other incidental noises.

The data taken during each trial may be conveniently divided into two types: records of learning and rec-

ords of activity. In the former class, the number of trials to learn and the errors involved in learning constitute the data. In the second class are the time from entrance into the reaction compartment to entrance into the food box after solution of the problem, the number of plates depressed, and the number of quadrants traversed. The last measure was obtained by dividing the floor of the box into four equal segments. Quadrant A included the area around the doors to and from the reaction compartment. The other sections (B, C, D) each contained one plate and adjoining floor space. These activity records were readily taken without marking off the floor of the box by noting the position of each of the four parts of the cage cover, the boundaries of which coincided with those of the various quadrants. Numerous types of incidental behavior, which could not be tabulated, were recorded by the experimenter during the course of each trial. Some use of these data will be made in the interpretation of the results.

Animals were run for seven days in the week, starting each day at the hour when the type used was most active. The white rats were tested from 7:30 P. M. to approximately 2:00 A. M. In the second experiment, the guinea pigs were run from 2:00 A. M. to about 9:00 A. M. These times agree with the finding of Nicholls (12) on differences in diurnal activity rhythms in rats and guinea pigs.

Norms of Mastery

Nine perfect trials in a sequence of ten was set as a norm of mastery. The attainment of lower norms was

noted, but no animal was set a more complicated problem *until* he had mastered a given step up to the highest norm. A perfect trial was one in which the subject proceeded directly to the correct plate or sequence of plates and then stopped or returned immediately to the door of the food box. Any movement indicating a tendency to continue on after the correct reaction without returning for food was listed as an imperfect solution. As soon as the norm of nine out of ten perfect trials had been attained, the animal was sent on to the next step. If, after 700 trials, a subject had not as yet solved the problem under the norm of mastery set, it was discarded and listed as having reached its limit. This number of trials, as the criterion of failure, was arrived at by preliminary research which showed that, in the animals tested, none that had failed to reach the norm in 500 trials succeeded in the next 200. Seven hundred trials was set, therefore, as the limit within which learning might take place. One exception to this general procedure was made. It occasionally happened that an animal failed to manifest any activity when in the reaction compartment. The three minutes were spent in merely sitting or in sniffing at the food box without any exploration or activity in the reaction compartment. When this occurred 100 times in succession in any step but the first, the animal was discarded. Very few subjects showed this consistent inactivity and when it occurred on the first step they were run 500 trials before being dropped so as to give them every opportunity to learn the step.

IV

RESULTS OF EXPERIMENT I

This experiment consisted in the training of 35 male albino rats on the three steps constituting the basic problem in the apparatus used. The first step necessitated the depressing of a single plate. This was situated to the right of the food box and will be hereinafter referred to as plate 1. When the norm of mastery of 9 perfect trials out of 10 had been attained, training on the second step was immediately begun. This involved learning to depress plates 1 and 2, the latter being to the rear of the reaction compartment. Step III was next set the animal. This consisted in the addition of plate 3 to the other two, the pattern being plates 1, 2, and 3 in sequence. In the second and third steps, correct solution was achieved only when the plates were depressed in the correct order without any intervening activity. Throughout the training period no extraneous cues such as electric shock or other punishment were supplied nor was any attempt made to enhance the value of the plates as stimuli. The indication of correct solution was the opening of the door to the food box subsequent to the depressing of the last plate in the sequence.

In Table 3 are given in detail the trial, time, and error scores of the individual rats tested in the basic problem under the norm of mastery described above. The first trial of the experiment is excluded in all the records in each column of the table since this was considered as a part of the preliminary training. The last

TABLE 3

SHOWING THE INDIVIDUAL TRIAL, TIME, AND ERROR RECORDS IN THE THREE STEPS OF EXPERIMENT I

The total time is shown in minutes and fractions of a minute. *F-I* includes rats which persisted in complete inactivity over a 3-*minute period* for over 100 trials. *F-II*—rats which persisted in activity over a 3-minute period without depressing the correct plate or plates *on* each of at least 100 trials. *F-III*—rats which failed to reach the norm of 9 perfect out of 10 consecutive trials in 700 attempts.

	Step I				Step II				Step III			
Rat number	Total trials	Total errors	Total time	Type of failure	Total trials	Total errors	Total time	Type of failure	Total trials	Total errors	Total time	Type of failure
1	400	730	278.13		700	2483	345.27	F-III				
2	700	1269	115.10	F-III								
3	148	222	173.51		700	1971	220.95	F-III				
4	143	170	226.58		432	1649	110.88		700	2378	606.71	F-III
5	100	71	175.21		160	589	31.58		700	2001	238.12	F-III
6	453	889	173.72		450	3183	138.60		700	1892	567.35	F-III
7	184	224	57.39		602	1468	697.40	F-I				
8	285	461	97.56		700	2135	112.91	F-III				
9	78	124	103.18		700	1694	213.13	F-III				
10	700	1460	129.24	F-III								
11	160	246	233.24		700	1816	926.90	F-III				
12	700	797	352.89	F-I								
13	440	360	105.29		700	2098	110.51	F-III				
14	700	968	76.29	F-III								
15	120	234	50.91		700	1998	186.27	F-III				
16	300	443	72.32		700	2395	154.67	F-III				
17	165	546	49.77		345	1161	87.30		700	2608	581.12	F-III
18	700	1369	802.67	F-II								
19	700	726	656.67	F-III								

TABLE 3 (*continued*)

		Step I			Step II				Step III			
Rat number	Total trials	Total errors	Total time	Type of failure	Total trials	Total errors	Total time	Type of failure	Total trials	Total errors	Total time	Type of failure
20	44	211	17.45		581	2402	54.40		700	2196	1412.60	F-III
21	354	577	243.52		700	3255	462.10	F-III				
22	250	294	256.21		700	1734	507.74	F-III				
23	700	988	645.02	F-III								
24	140	390	52.42		700	1699	115.21	F-III				
25	700	1058	109.71	F-III								
26	360	1242	90.20		700	1273	112.83	F-III				
27	320	274	350.21		161	1280	58.55		700	1854	978.31	F-III
28	30	100	12.03		341	1475	86.41		700	2250	1063.67	F-III
29	700	1287	354.06	F-III								
30	280	750	91.87		252	1267	80.10		700	2105	796.33	F-III
31	203	1038	126.67		700	1816	871.15	F-III				
32	700	2564	105.00	F-III								
33	700	2117	97.31	F-III								
34	188	886	43.47		700	1971	126.97	F-III				
35	204	815	45.67		700	2807	616.27	F-III				

8 or 9 trials of the norm of mastery are also excluded. That is, records cover the period from the second trial given each animal through to the first trial of the criterion series, provided that the latter was perfect. If the subject made an error on a trial and then ran successfully for 9 consecutive times, the record will include the first two of the 10 trials of the norm.

The first column in Table 3 under each step gives the total number of trials taken in the solution of that step. In the second column are given the total error scores, the various types of which will be discussed in connection with Table 7. The total time in minutes spent in the reaction compartment prior to entrance into the food box is given in the third column. The last column under each step shows the type of failure for which the individual animal was finally discarded. Failure I means that these animals showed complete inactivity over a three-minute test period throughout a sequence of at least 100 trials. That is, the subjects did not, on such trials, move out of the front quadrant surrounding the doors to the entrance and food boxes. In such cases, the time was spent mainly in washing, licking, or scratching, but no exploratory behavior or excursion into other quadrants was observed. Failure II means failure to depress the correct plate or plates within the three-minute period constituting each trial for at least 100 trials. The rats were active and ran around from quadrant to quadrant, depressing one or more plates, but they displayed no evidence of a definite plate habit. Such animals were not rewarded immediately with food at the end of the trial but were re-

placed in the entrance box and given another trial. After 5 trials in which this non-adaptive behavior was shown, the rats were replaced in the feeding-cages and further penalized by being restricted to one-half of the usual ten-minute feeding period after the successful rats in this cage had been fed. Failure III was the most common of all and involved the inability of the rat to reach the norm of 9 correct reactions in 10 consecutive trials during the course of the entire experiment. This type of failure was checked against an animal only after 700 trials had been run. Only those rats which learned under the norm described above were advanced to the next higher step. The lacunae in the table are to be accounted for by the dropping-out of the animals that showed one or another of the various types of failure.

Several facts stand out in an examination of Table 3. In the first place, it may readily be seen that, under the conditions set, the limit of learning was reached on the second step of the basic problem. None of the rats tested learned the third step. It will be noticed also that the groups showed extreme variability in all of the measures indicated. In Step I the scores for the animals which learned ranged from 30 to 453 trials, 100 to 1242 errors, and 12 to 330 minutes. In Step II the corresponding ranges are from 160 to 432 trials, 598 to 3183 errors, and 31 to 220 minutes. It will be seen that all of these ranges rise in the second step over the first. Since none of the animals reached the norm of mastery on Step III, the corresponding data for this stage are not available.

TABLE 4

SHOWING THE TOTAL NUMBER OF RATS USED AND THE NUMBER AND PERCENTAGE COMPLETING EACH STEP UNDER THE THREE NORMS OF MASTERY

Norm 1 is 9 perfect trials in a sequence of 10. *Norm 2* is 4 perfect trials in a sequence of 5. *Norm 3* is 1 perfect trial in a sequence of 2.

		Step I	Step II	Step III
	Total number used	35	24	8
Norm 1	Number which learned	24	8	0
	Percentage which learned	69	33	0
Norm 2	Number which learned	34	14	3
	Percentage which learned	97	58	38
Norm 3	Number which learned	35	24	8
	Percentage which learned	100	100	100

Table 4 gives the number and percentage of rats which successfully completed each step. Only the data under Norm 1 are pertinent to the present discussion. The arrays representing the two lower norms were calculated in order to bring out certain comparative information about rats and guinea pigs and will be discussed in Chapter VI. It will be seen that over two-thirds of the group under the highest norm succeeded in Step I. Of this 69 per cent, one-third learned Step II. None of these animals was successful in attaining the third step despite the fact that the increase in complexity involved no change in the mode of response required for solution but merely an extension of a previously acquired habit. The limit of learning for the group of rats tested was, therefore, established at two steps. A cursory scanning of the lower arrays shows that, had the norm of mastery been lowered to 4 out of 5 perfect trials, the percentage of rats learning

each step would have been materially increased. Norm 3 represents a very low criterion and is included here mainly to show that the problem was sufficiently simple so that all of the rats could make at least one perfect response.

The measures of central tendency and variability for the data collected on learning and activity are given in Tables 5, 6, 8, and 9. The number of trials required to learn the various steps of the basic problem is given in Table 5. It can be seen that both the median and

TABLE 5

SHOWING THE NUMBER OF TRIALS TO LEARN THE FIRST TWO STEPS OF THE BASIC PROBLEM IN EXPERIMENT I

The data for Step III are omitted since the 8 rats which learned Step II failed on the next higher step.

Step	N	Range	Trials to learn Median	Average	A.D.	S.D.
I	24	30-453	196.00	221.04	99.97	129.26
II	8	160-450	363.00	315.25	93.19	116.77

average number of trials to learn Step II show increases over the corresponding measures for Step I. The ratio of the differences to the reliability of these differences in average scores is 1.94. This means that there are 97 chances in 100 that the true difference between the averages in Steps I and II is greater than zero. It follows, therefore, that more practice was required to master a problem necessitating the depression of two plates in a given order after the first had already been learned than for the depression of a single plate. The large differences between the averages and medians in each step and also the wide scatter shown in the average

and standard deviations may be accounted for by a few extreme cases which influence the distribution considerably. If, in Step I, the 5 animals whose scores are below 100 or above 400 trials are excluded, the range is reduced by approximately one-third and much of the variability is eliminated. In Step II, the exclusion of the 3 rats whose scores are below 300 reduces the range by over 50 per cent. In general, despite the smaller number of animals tested in the second step, the measures of dispersion show that this group is slightly more homogeneous than that used on the first step. Tables 6 and 7 give the data on errors and failures. In the former table are shown the measures of central tendency and variability for total errors, total errors per trial, and the first two types of failure de-

TABLE 6

SHOWING THE TOTAL ERRORS, FAILURES, AND TOTAL ERRORS PER TRIAL ON THE FIRST TWO STEPS OF THE BASIC PROBLEM IN EXPERIMENT I

The data for Step III are omitted since the 8 rats which learned Step II failed on the next higher step. *Failure I*—complete inactivity over a period of three minutes; *Failure II*—activity over a three-minute period without depressing the correct plate or plates.

Step	N	Errors	Range	Median	Average	A.D.	S.D.
I	24	Total errors	71-1242	375.00	470.71	173.86	217.85
		Failures I	0-73	2.00	10.58	12.91	16.18
		Failures II	0-15	.50	2.46	2.91	3.65
		Total errors per trial	.75-5.11	1.73	2.31	1.14	1.43
II	8	Total errors	589-3183	1377.50	1625.75	575.94	721.65
		Failures I	0-4	0.00	0.50	.85	1.12
		Failures II	0.00	0.00	0.00	0.00	0.00
		Total errors per trial	3.37-7.95	4.65	5.19	1.43	1.79

TABLE 7

SHOWING THE FREQUENCY OF VARIOUS TYPES OF ERRORS ON THE FIRST TWO STEPS OF EXPERIMENT I

In Step I the omission of plate 2 and the depression of plate 1 were not tallied as errors.

Types of error		Average Step I	Average Step II	Frequency per trial Step I	Frequency per trial Step II
Omissions of	Plate 1	278.83	434.00	1.26	1.38
	Plate 2	.....	243.25	...	0.77
Depressions of	Plate 1	.....	87.63	...	0.28
	Plate 2	12.79	94.50	0.06	0.30
	Plate 3	19.50	49.50	0.09	0.16
Delay at door of	Food box	149.79	570.63	0.64	1.81
	Entrance box	9.79	1.13	0.04	0.004

scribed above in the discussion of individual scores. Table 7 gives a detailed analysis of the various components of the total error array in the preceding table. It will be noticed that the same tendency demonstrated in the discussion of trial scores is apparent also in Table 6. Just as more trials were required to learn Step II than Step I, so here we find more errors in the mastery of the second step. The increase in difficulty of Step II over Step I holds for both total errors and for average errors per trial. That these differences are reliable is shown by the ratio of the differences to the standard deviation of the difference which is 4.46 for the former and 4.11 for the latter set of scores. This means that there are 100 chances in 100 that the true difference is greater than zero. The same degree of certainty of a true difference between records on Steps I and II exists also for the two classes of failures. It will be noticed, however, that, whereas the other measures show in-

creases in Step II over Step I, both varieties of failure decrease in frequency in the second step. It seems that as the animals become more accustomed to the problem they show less tendency to indulge in non-exploratory activity. Any failure due to inactivity disappears almost completely by the time the second step is reached (Failure I). Moreover, no animals failed in this step by omitting to depress a plate or plates during the trial (Failure II). Since the 3 animals which made the most failures of type I in the first step had no such records checked against them in Step II, this decrease in non-exploratory behavior cannot be said to arise from the elimination in Step II of animals which scored failures in Step I.

An analysis of total error scores into 3 large classes in each step is given in Table 7. The specific errors which could be tabulated in Step II are necessarily larger in number than those in Step I since the addition of a plate increased the possibility of incorrect responses. The additional types of error in the second step are the omission of plate 2 and the depression of the same plate. An examination of the table will show that the order of diminishing frequency of occurrence of the various errors in Step I is as follows: (*a*) omission of plate 1, (*b*) delay at the door to the food box, (*c*) depression of plate 3, (*d*) depression of plate 2, and, last, (*e*) delay at the door to the entrance compartment. In Step II the same general trend is noticeable with two exceptions. The most frequent error was that of delay at the door of the food box, the omission of plate 1 assuming second place. There fol-

low in order then: omission of plate 2, depression of plate 2, of plate 1, and of plate 3, and, finally, delay at the door to the entrance box. The importance of the food-box door as a distracting stimulus is easily understood, since running to the opening constituted the terminal activity of each successful trial. Hence, in many cases, obtaining the reward was associated with running to the inner door rather than with the touching of a plate. This explains the increasing frequency of this error in Step II since these animals had many more trials in which they received food after entering through the open doorway. All of the types of error discussed in the table are associated with the behavior required in the solution of the problem. There is an almost complete lack of such activity as was not related to solution. Only two rats were observed attempting to climb the walls of the reaction cage and this occurred in a few trials only. Among other errors which happened so rarely as not to warrant their inclusion in the table were such types of activity as chewing at the sides of the reaction compartment, sniffing at the edges of the plates, and refusal to enter the food cage even after the door had been opened. The latter error was the most frequent of this class and occurred but 12 times for all animals. All of these varieties of incorrect responses took place in the first third of the training period and disappeared as the rats became more accustomed to the apparatus and problem.

The data on time and activity in the first two steps of the problem are given in Tables 8 and 9. Under activity records are included quadrants, plates, quad-

TABLE 8

SHOWING THE TIME AND ACTIVITY ON THE FIRST TWO STEPS OF THE BASIC PROBLEM IN EXPERIMENT I

The data for Step III are omitted since the 8 rats which learned Step II failed on the next higher step.

Step	N	Time and activity	Range	Median	Average	A.D.	S.D.
I	24	Time in minutes	12-230	100.37	129.39	77.09	96.59
		Quadrants	241-3921	1160.00	1379.33	609.05	763.14
		Plates	54-450	249.00	241.68	107.25	134.38
		Quadrants per min.	2.77-40.50	15.96	16.33	8.94	11.21
		Plates per min.	.42-5.80	2.97	2.65	1.35	1.69
II	8	Time in minutes	32-139	83.26	81.00	24.85	31.14
		Quadrants	1502-7803	2904.00	3592.75	1386.50	1737.28
		Plates	421-1269	766.50	861.12	229.13	287.10
		Quadrants per min.	5.21-56.22	40.66	38.86	9.73	12.19
		Plates per min.	2.09-9.87	9.20	8.43	1.62	2.03

TABLE 9

SHOWING THE NUMBER OF COMPLETE CIRCUITS (CLOCKWISE AND COUNTERCLOCKWISE) AROUND THE FOOD BOX IN THE FIRST TWO STEPS OF EXPERIMENT I

The data for Step III are omitted since the 8 rats which learned Step II failed on the next higher step.

Step	N	Direction of activity	Range	Median	Average	A.D.	S.D.
I	24	Clockwise	13-369	61.00	75.12	41.34	51.80
		Counterclockwise	1-290	8.00	32.58	38.97	48.53
II	8	Clockwise	89-554	215.50	259.63	139.53	174.83
		Counterclockwise	5-486	39.00	179.50	184.31	230.94

rants per minute, plates per minute, clockwise and counterclockwise circuits around the food box. Inasmuch as the two latter varieties of scores represent direction rather than amount of activity, they are presented by themselves in Table 9. Considering first the time taken in solution of Steps I and II, it will be seen that this measure produces a relationship inverse to that which holds when trials and errors are taken as indices of learning. Step II required more trials and involved more errors than did Step I but was mastered in less time than the easier step. That this discrepancy is not due to chance is shown by the reliability ratio of the difference between the time averages on the two steps. This is 2.15, which indicates 98 chances in 100 of a true difference greater than zero. It is evident, therefore, that time to learn and trials to learn measure different aspects of the problem-box situation. The former record is more accurately to be described as an index of speed of activity whereas trials and errors constitute a better index of learning as such. That this is

indeed the case may readily be seen by referring to the other arrays in Table 8.

When the data on quadrants and plates are examined, it is obvious that the rats were much more active on the second step than on the first. Not only did they traverse 2.60 times as many quadrants but they also depressed 3.56 times as many plates on the average in the second step. These increases in activity are clearly brought out in the arrays for quadrants per minute and plates per minute. For the 16.33 quadrants traversed per minute in the first step, there are 38.96 in the second, and likewise the number of plates depressed per minute increases from 2.65 in the first to 8.43 in the second step. All of the above increases are highly reliable, the chances of a true difference greater than zero being 100 in 100 in each instance. In other words, as the rats became more familiar with the problem, they ran much faster and in so doing made more errors, thereby *increasing the number of trials necessary to reach the* norm of mastery. The variability for all measures of activity other than time also shows large increases in the second step. Another cause for the large activity records on the higher step is the dropping-out of failures due to inactivity. Since each trial on which an animal failed because of the first type of failure lasted the maximum of 3 minutes, this would tend to increase the time and decrease the number of quadrants and plates in the first step.

In view of the extensive discussion of direction of movement in white rats, it is interesting to note the results given in Table 9. The data in this table give the

number of times that the animals ran completely around the food box without stopping at the correct plate although in such circuits they may have depressed one or more plates. It can be seen that the number of clockwise or left-going circuits in both steps is reliably greater than that for the opposite direction. These results are to be compared with those of Gengerelli (3) and Yoshioka (19) on direction of movement in albino rats. The former investigator found that 79 and 61 per cent of the groups tested manifested right-going tendencies. The latter experimenter found evidence of correlation of direction of movement with the direction of curvature of the nasal bones. While the data found in the present experiment seem to be contradictory to those found by others, it must be borne in mind that the facts presented in Table 9 hold only for activity during complete encircling of the food box. Over 62 per cent of this activity took place in the first two-fifths of the learning period. During the remainder of the course of learning, the tendency changed toward movement to the right. The cause for this is undoubtedly the fact that the correct reaction in both steps involved the initial depressing of the right-hand plate. With increasing frequency of correct responses, there was manifested a change in direction favorable to the inception of correct habits.

The percentages of total errors and total time in the successive tenths of the training period are given in Table 10 for the rats which learned the two steps. The derivation of this table follows the method for constructing a learning curve as suggested by Vincent (15)

TABLE 10

SHOWING THE PERCENTAGE OF TOTAL TIME AND ERROR IN THE SUCCESSIVE TENTHS OF THE TOTAL TRIALS TO LEARN THE FIRST TWO STEPS IN EXPERIMENT I

Tenths of total trials	Percentage of total time	Percentage of total error	Percentage of total time	Percentage of total error
1	28	35	15	22
2	19	21	12	18
3	15	16	10	12
4	12	9	14	11
5	9	5	10	9
6	7	4	10	7
7	3	3	8	8
8	3	2	7	6
9	2	3	8	4
10	2	2	6	3

and modified by Loucks (8). The first column represents successive tenths of the total trials to learn the step and the other columns present the percentage of total time and total errors in each tenth of the learning period. It will be noticed that, in the first step, both errors and time show a typical decrease as the amount of practice increases. The data, if put into graphic form, would resemble the ordinary learning curves. In Step II, however, the time scores are much more nearly constant than they were in the first step and are radically different in trend from the error scores in the second step. That is, although learning is going on as manifested by the decrease in error scores, time does not show much lessening in amount. The total decrease in time is 9 per cent, that for errors is much greater, being 19 per cent. This bears out in part the contention made in the discussion of time as an index of activity. It seems that as soon as practice has familiarized an animal with the problem his speed of movement becomes more constant.

Summary

1. The limit of learning for white rats was found to be the second step of the basic problem under the norm of mastery of 9 perfect out of 10 consecutive trials. Sixty-nine per cent of the rats learned the first step and 33 per cent of these mastered the second under the norm described above. It seems likely, however, that the limit of learning would have been higher than this under lower norms.

2. The group averages show extreme variability. This was reduced markedly in the case of trial, time, and error scores by the omission of a few extreme cases.

3. Trial and error scores were found to be better indices of learning than time whereas the latter furnished an adequate measure of activity.

4. Rats were found to display marked activity during the problem. The activity increased considerably in the second step over the first as measured by the number of quadrants traversed and the number of plates depressed.

5. Under certain conditions white rats seem to show a preference for going to the left rather than to the right. This was noted especially in the circuit movements around the food box during which the correct sequence of plates was not depressed.

V

RESULTS OF EXPERIMENT II

This experiment consisted in the training of 30 male guinea pigs on the various steps of the basic problem described in the preceding chapter. The procedure throughout the experimental period was identical for both rats and the subjects of the present discussion except for the instances noted in the sections on methods and procedure (Chapters II and III). All scores found in Tables 11, 12, 13, 14, and 15 are derived in the same fashion as for the rats and are strictly comparable to those for the latter group. The meanings of the various terms in the tables are likewise the same for both groups of animals. The material reported in the present chapter is restricted to the data obtained from the guinea pigs as subjects. The comparison of the two classes of rodents with each other and with certain higher mammalian forms will be found in Chapter VI.

Table 11 gives in detail the trial, error, and time scores of all of the guinea pigs tested on the first two steps of the problem. The norm of mastery, namely 9 perfect trials out of 10, is the same as was used with the rats. It may be seen, upon inspection, that no guinea pigs learned the second step although 16 of the group successfully attained the norm on the first step. The limit of learning for guinea pigs is, therefore, one step in the apparatus used. Another fact which stands out is the large variability displayed in all of the indices shown in the table. The range in scores in Step I, for the animals which learned, was from 53 to 407

TABLE 11

SHOWING THE INDIVIDUAL TRIAL, TIME, AND ERROR RECORDS IN THE TWO STEPS OF EXPERIMENT II

The total time is shown in minutes and fractions of a minute. *F-I* includes guinea pigs which persisted in complete inactivity over a 3-minute period for over 100 trials. *F-II*—guinea pigs which persisted in activity without depressing the correct plate or plates over a 3-minute period for over 100 trials. *F-III*—guinea pigs which failed to reach the norm of 9 perfect out of 10 consecutive trials in 700 attempts.

Guinea pig number	Step I Total trials	Step I Total errors	Step I Total time	Step I Type of failure	Step II Total trials	Step II Total errors	Step II Total time	Step II Type of failure
1	120	379	166.67		700	923	297.04	F-III
2	700	434	431.67	F-I				
3	700	1054	671.47	F-III				
4	700	403	106.29	F-III				
5	237	714	96.21		700	1002	725.67	F-III
6	107	228	40.43		700	759	401.14	F-III
7	700	1035	792.67	F-III				
8	407	484	191.21		682	788	500.11	F-I
9	156	840	72.35		700	1491	166.27	F-III
10	104	438	18.63		700	940	115.41	F-III
11	505	294	620.00	F-I				
12	700	590	650.42	F-III				
13	700	249	506.67	F-III				
14	103	153	60.87		517	678	607.50	F-I
15	700	798	105.50	F-III				
16	243	154	130.73		700	1186	205.81	F-III
17	184	67	102.50		700	665	516.67	F-I
18	91	89	45.30		504	756	925.15	F-I
19	664	549	485.67	F-I				
20	90	72	44.03		700	678	304.14	F-III
21	700	131	592.35	F-III				
22	53	43	31.33		700	2565	112.85	F-III
23	700	1106	801.67	F-III				
24	121	110	51.05		700	796	145.67	F-III
25	182	135	106.51		675	410	540.01	F-I
26	700	412	175.50	F-III				
27	404	150	105.67		700	1663	211.33	F-III
28	700	471	961.12	F-III				
29	700	1198	432.33	F-III				
30	367	196	76.45		700	986	321.27	F-III

trials, 43 to 840 errors, and 31 to 191 minutes. Corresponding measures for the higher steps do not indicate learning inasmuch as no animals satisfied the norm of mastery on Step II and will hence not be discussed here.

The same three types of failure were checked against the guinea pigs as had been found to occur with rats as subjects. The most frequent type for which any animal was discarded was Type III which involved the inability to reach the norm in 700 trials. The next type of failure was that of inactivity for the duration of each of at least 100 trials (Type I). No animals were discarded in either step because of failure to depress the correct plate or sequence of plates during continued activity on each of at least 100 trials (Failure II). The number discarded for Failure I was smaller in the first step (21 per cent) than in the second (41 per cent). This indicates that, despite increasing familiarity with the problem and apparatus, exploratory behavior diminished as the limit of learning was approached. The guinea pigs seemed to lose orientation toward the plates and the rear of the box in increasing amount as they made continued incorrect responses.

The number and percentage of the group of animals tested which successfully completed each step are given in Table 12. Only the data under Norm 1 will be referred to here since no animals which attained lower norms were actually advanced to the next higher step. It can be seen that 53 per cent of the 30 animals originally used reached the norm on Step I and were passed

TABLE 12

SHOWING THE TOTAL NUMBER OF GUINEA PIGS USED AND THE NUMBER AND PERCENTAGE COMPLETING EACH STEP UNDER THE THREE NORMS OF MASTERY

Norm 1 is 9 perfect trials in a sequence of 10. *Norm 2* is 4 perfect trials in a sequence of 5. *Norm 3* is 1 perfect trial in a sequence of 2.

		Step I	Step II
	Total number used	30	16
Norm 1	Number which learned	16	0
	Percentage which learned	53	0
Norm 2	Number which learned	27	9
	Percentage which learned	90	56
Norm 3	Number which learned	30	15
	Percentage which learned	100	94

on to the second step. From an examination of the other arrays in the table it appears likely that, had the criterion of mastery been lowered, the animals might have reached a higher limit of learning.

The measures of central tendency and variability for trials to learn, errors, failures, time, and other records of activity are given in Tables 13 and 15. The upper

TABLE 13

SHOWING THE NUMBER OF TRIALS TO LEARN, TOTAL ERRORS, ERRORS PER TRIAL, AND FAILURES ON THE FIRST STEP OF EXPERIMENT II

The data for Step II are omitted since the 16 guinea pigs which learned Step I all failed on the next higher step. *Failures I*—complete inactivity over a period of 3 minutes; *Failures II*—activity over a 3-minute period without depressing the correct plate.

Scores	Range	Median	Average	A.D.	S.D.
Trials	53-407	151.50	185.50	110.69	176.28
Total errors	43-840	153.50	265.81	183.87	230.39
Failures I	0-25	4.00	8.44	7.35	9.21
Failures II	0-10	2.00	2.81	2.12	2.66
Total errors per trial	0.36-5.38	.91	1.54	1.54	1.85

array in the first of these two tables gives the number of trials taken to attain the highest norm of mastery in Step I. The variability here is almost as large as the central tendency indicated by the average score. If the 3 animals whose scores are above 300 trials are eliminated, the range is reduced by 46 per cent and the variability is thus greatly diminished. In like manner the variability for errors, failures, and the other scores also depends upon a few extreme cases. The range of errors is reduced by approximately 50 per cent through the exclusion of the 3 guinea pigs whose scores are above 450. Failures I and II, in this table, refer to isolated occurrences of the same types of behavior, for the repeated appearances of which animals were discarded. That is, the group which learned Step I made an average of 8.44 trials in which they displayed no exploratory behavior for the 3-minute duration of each trial. This is reliably greater than the number of trials in which the animals were active but failed to depress the correct plate within the limit of each trial (Failure II).

The analysis of the total error array of Table 13 is given in Table 14. The order of diminishing fre-

TABLE 14

Showing the Frequency of Various Types of Errors on the First Step of Experiment II

Types of errors		Average	Frequency per trial
Omission of plate 1		168.38	0.91
Depression of	plate 2	19.06	0.10
	plate 3	21.75	0.12
Delay at door of	food box	23.25	0.13
	entrance box	2.06	0.01

quency of the various types of error is as follows: (*a*) omission of plate 1, (*b*) delay at the door to the food box, (*c*) depression of plate 3, (*d*) depression of plate 2, and (*e*) delay at the door to the entrance box. Among the varieties of incorrect responses which appeared so rarely as to make difficult their inclusion in the table, the most frequent was chewing or gnawing at the wire mesh at the rear of the food box, that is in quadrant B. Other such infrequent errors were standing on the hind feet with the forefeet resting on the wall of the inner cage, refusal to enter the open door to the food box after depression of the correct plate, "freezing" (which refers to the cessation of behavior by an animal for a short space of time), and chewing at the wall of the outer cage. These are listed in the order of decreasing frequency, the range of occurrence being from 10 to 1. The interpretation of these errors is essentially the same as that given above for rats.

The various measures of activity are given in Table 15. Those which deal with amount rather than direc-

TABLE 15

SHOWING THE TIME, AMOUNT, AND DIRECTION OF ACTIVITY ON THE FIRST STEP OF EXPERIMENT II

The data for Step II are omitted since the 16 guinea pigs which learned Step I all failed on the next higher step. *Clockwise* and *counterclockwise* refer to the number of complete circuits around the food box in each of the directions indicated.

Time and activity	Range	Median	Average	A.D.	S.D.
Time in minutes	40-191	74.40	83.28	39.19	49.10
Quadrants	*261-1982*	*940.00*	*1098.19*	*542.21*	*679.39*
Plates	63-437	168.00	217.88	103.97	130.27
Quadrants per min.	*5.44-54.20*	*11.99*	*15.99*	*8.42*	*10.55*
Plates per min.	.80-9.72	2.49	3.11	1.24	1.55
Clockwise circuit	4-118	21.00	29.19	20.76	26.01
Counterclockwise circuit	1-58	7.50	14.25	11.59	14.52

tion of movement are found in the arrays above the central vertical line. From a general examination of the data presented in the upper arrays, it can be seen that the guinea pigs as a group manifested considerable activity. A good indication of this may be had by comparing the average trials to learn with the average time scores. This shows that the average time per trial was 0.45 minute. When time scores are thus compared with trials and errors, it becomes apparent that, just as was the case with rats, time represents a better index of speed of activity than it does of learning. This is also brought out in the number of quadrants traversed per minute. An average of almost 16 quadrants was traversed per minute and yet, during all of the activity, only 3.11 plates were depressed. The ratio which would occur were an animal to enter all quadrants and step on all plates would be 4 quadrants to 3 plates. As learning proceeded to the point of solution, this ratio would be reduced to 2 quadrants to one plate. That is, the guinea pig would have to move through the front quadrant and into the one containing plate 1 before depressing that plate. The guinea pigs actually traversed an average of 15.99 quadrants to 3.11 plates, a ratio of 5.14 to 1. This indicates an excess of activity not directed toward the depressing of plates and thus not conducive to the establishment of behavior favorable to solution.

The lower arrays show the amount and direction of activity during the continuous encircling of the food box within a single trial. In such cases, the guinea pigs ran around the inner cage, without depressing or

even stopping at the correct plate or plates. It can be seen that there is a slight tendency for left-going movements to predominate in these situations. That this indicates a preference for left-going is a conclusion which cannot be drawn from the data at hand. The type of behavior noted in Table 15 does not represent all of the starts in either direction that were made by the group. It is, however, suggestive of the necessity of investigating directional choice when the reward is placed between the two pathways and not at the end of an apparatus.

TABLE 16

Showing the Percentage of Total Time and Error in the Successive Tenths of the Total Trials to Learn the First Step of Experiment II

Tenths of total trials	Percentage of total time	Percentage of total errors
1	28	22
2	18	16
3	14	12
4	8	10
5	6	9
6	7	10
7	5	8
8	5	5
9	4	4
10	5	4

Table 16 gives the data for the percentage of total errors and total time in the successive tenths of the training period for the 16 guinea pigs which learned Step I. The table, which was constructed along the lines of Loucks' modification of the Vincent learning-curve method, is similar to that discussed in connection with the corresponding rat data. The scores in the

table represent the percentage of the total time and errors which is to be found at a given point in the acquisition of the habit. It will be noticed that, whereas time becomes practically constant after the first three tenths, the error scores continue to decrease and do not become constant until 90 per cent of the total trials have been given the group. The fact that the successive error and time scores show these discrepancies may be taken to indicate that both records are not measures of the same phase of the learning process. Error scores may be considered as measures of the pattern formation here studied while time is a measure of activity.

Summary

1. The limit of learning for guinea pigs was found to be the first step of the basic problem under the norm of mastery of 9 perfect out of 10 consecutive trials. Only 16 of the 30 guinea pigs tested met this condition. It seems likely, however, that the limit of learning would have been higher than this under lower norms.

2. The group averages show extreme variability. This was reduced markedly in the case of trial, time, and error scores by the omission of a few extreme cases.

3. Trial and error scores were found to be better indices of learning than time whereas the latter furnished an adequate measure of activity.

4. The previous findings of Nicholls and others on the great amount of activity manifested by guinea pigs were borne out by the number of quadrants traversed and the speed of movement shown in the apparatus.

5. Under certain conditions, guinea pigs seem to show a preference for going to the left rather than to the right. This was noted especially in the circuit movements around the food box during which the correct sequence of plates was not depressed.

VI

COMPARISON OF TYPES

RODENTS

From the facts presented in the two preceding chapters, it can be seen that white rats are able to reach a higher limit of pattern-habit formation than guinea pigs. The limit found for the former group was the second step, that for the latter the first step of the basic problem. The number of subjects tested and the records of each group on the various steps are given in Table 17. The data for the three norms in Step I

TABLE 17

SHOWING THE TOTAL NUMBER OF ANIMALS USED AND THE NUMBER AND PERCENTAGE COMPLETING EACH STEP UNDER THE THREE NORMS OF MASTERY IN EXPERIMENTS I AND II

Norm 1 is 9 perfect trials in a sequence of 10. *Norm 2* is 4 perfect trials in a sequence of 5. *Norm 3* is 1 perfect trial in a sequence of 2.

		Step I Rats	Step I Guinea pigs	Step II Rats	Step II Guinea pigs	Step III Rats	Step III Guinea pigs
Total number used		35	30	24	16	8	0
Norm 1	Number which learned	24	16	8	0	0	..
	Percentage which learned	69	53	33	0	0	..
Norm 2	Number which learned	34	27	14	9	3	..
	Percentage which learned	97	90	58	56	38	..
Norm 3	Number which learned	35	30	24	15	8	..
	Percentage which learned	100	100	100	94	100	..

represent actual learning scores under these criteria. That is, the various arrays give the data incidental to learning under norms of 9 perfect trials in 10, 4 perfect

trials in 5, and 1 perfect trial in 2 consecutive trials. The lowest criterion is included here for the sake of completeness but, since it is so greatly affected by chance success, it will be omitted from the present discussion.

A comparison of the results shows that the higher norm was more selective in the case of the guinea pigs than in the case of the rats. This is true whether we consider absolute or relative percentages. A larger percentage of rats than guinea pigs learned both steps under both norms. However, more of the guinea pigs were eliminated in both steps by the use of the higher norm than were rats. The percentage of the former group thus eliminated was somewhat greater than for the rats in Step I, and more than twice as great in Step II. It should be noted, however, that the values for the lower norms in Step II were computed only after the animals had actually attained Norm 1 on Step I. *It seems likely, therefore, that some of the guinea pigs* might have mastered the second step had the lower norm been used. Moreover, under the same conditions, it is probable that some of the rats would have advanced to the third step. This shows that the limits found for the two types of rodents were not a function of the specific norm of mastery actually used, i.e., 9 perfect out of 10 consecutive trials.

The data in Table 18 show that in the easier task (Step I) the guinea pigs are superior to the rats in terms of total trials to learn, under both norms. A similar tendency was shown in the total error and time scores. This contention is further corroborated by the

TABLE 18

SHOWING THE INFLUENCE OF DIFFERENT NORMS OF MASTERY ON THE LEARNING OF RATS AND GUINEA PIGS IN TERMS OF TOTAL TRIALS

Norm 1 is 9 perfect trials in a sequence of 10. *Norm 2* is 4 perfect trials in a sequence of 5. *Norm 3* is 1 perfect trial in a sequence of 2. Norm 1 is omitted in Step II because no guinea pigs attained that degree of mastery in 700 trials.

Norm	Group	N	Range	Median	Average	A.D.	S.D.
			STEP I				
1	Rats	24	30-453	196.00	221.04	99.97	125.26
	Guinea pigs	16	53-407	151.50	185.50	110.69	176.28
2	Rats	34	12-650	188.50	223.30	115.69	144.50
	Guinea pigs	27	21-515	138.00	169.60	90.32	113.79
3	Rats	35	5-204	73.00	72.81	37.32	46.76
	Guinea pigs	30	2-208	39.00	57.28	41.19	51.62
			STEP II				
2	Rats	14	62-517	220.75	226.39	104.38	131.41
	Guinea pigs	9	27-406	248.00	257.00	117.33	147.01
3	Rats	24	1-204	54.50	58.66	35.45	47.38
	Guinea pigs	15	4-272	70.00	86.00	52.78	64.06

fact that 69 per cent of the guinea pigs under Norm 1 and 53 per cent under Norm 2 required fewer trials to learn than the median rat.

The relative efficiency of learning for the two types of rodents follows the reverse trend, however, when the more difficult task (Step II) is considered. The facts under the higher norms are omitted in Table 18 since none of the guinea pigs acquired this degree of proficiency. In Step II, 60 per cent of the guinea pigs required more trials to learn than the median rat under Norm 2. Similar results are obtained from the comparison of total errors and time. As the problem set approaches the limit of learning, it becomes relatively

more difficult to master, requires more activity and involves more errors.

In addition to the learning scores, differences occurred also in activity and other types of behavior. The latter were chiefly qualitative in nature and therefore difficult to tabulate and treat statistically. These may be classified in two ways: (*a*) behavior leading to solution and (*b*) behavior detrimental to solution of the problem. Under the first heading are included such types of activity as sniffing at the plates, depressing the plates with the forefeet, with the hind feet, and the establishing of definite quadrant habits. Under the second heading are found behavior disturbances, cessation of activity, mechanization of responses, and the fixation of incorrect habits. With reference to the first of the subtypes of activity leading to solution, it was noticed that in 87 per cent of the trials the rats sniffed at one or more plates whereas the guinea pigs exhibited equivalent behavior in only 28 per cent of the trials given them. Whether this indicates that olfaction is better in the former group than in the latter cannot be established from this experiment. As far as can be found from examination of the literature concerning smell in the two types of rodents, there is no definite evidence of difference in olfactory sensitivity. The data on this receptor capacity are scarce and when found are not consistent. Liggett (7), in a careful study of olfaction in the white rat, finds it to be poor under the conditions of his research. Neurologically, the olfactory equipment of the two groups of rodents seems to be about equal. In view of the absence of in-

formation on the rôle of smell in the learning of guinea pigs and the conflicting evidence in rats, it would seem that the data on sniffing in rats represent merely a difference in the frequency of employment of this sense modality in exploratory behavior and do not prove the existence of differential sensitivity.

The rats were also much more likely to depress the correct plate or plates with the forefeet or the hind feet alone than were the guinea pigs. That is, the former group of subjects more frequently stepped on a plate with either pair of pedal appendages alone than with the entire body. The guinea pigs, on the other hand, showed no evidence of this type of short-circuit behavior. They ran on to the plates and depressed them with the weight of the entire body just as frequently as they used the front or the hind feet. In general, these results for the guinea pig seem to bear out the findings of Muenzinger and his collaborators (10, 11) on plasticity of behavior during long continued practice periods. These investigators found that guinea pigs tend to maintain great variability in the specific methods by which the problem was solved despite the fact that they were given 600 to 1000 trials in which to mechanize the mode of attack.

The most noticeable differences between the two groups appeared in the behavior disturbances of the second class described above. In general, guinea pigs were more likely to manifest irritability and disruption of activity than rats. On certain occasions the former animals would seem to become immobile. This "freezing" of the subjects involved rigidity of the body

with the head fixed in the direction of movement and breathing markedly retarded in frequency and depth. Such cessation of activity took place under many conditions. It was most apt to occur when such infrequent extraneous noises as the dropping of a pencil or the shifting of the experimenter in his chair impinged upon the subject. However, auditory stimuli were not the only causes of this behavior. When the animals were touched by the door to the entrance or food box as it closed behind them, at the change from Step I to Step II and under other similarly novel or unusual circumstances, the same disturbance was noted. Rats did not manifest any behavior remotely resembling this "freezing" of the guinea pig although the same incidental stimuli giving rise to it, in the case of the latter group, were also present for the rats. It was thought, at first, that a partial explanation of this phenomenon was that rats were not as susceptible to auditory distraction as were guinea pigs since the cochlea of the latter turns 5 times about its axis as compared to 2.5 times in the case of the rats. No evidence is found in the literature covering audition which can be adduced to settle this point. Wever (18), in a study of impulses from the auditory nerve of guinea pigs and rats, finds no differences in his subjects either in the tones to which responses were obtained or in the reaction to the human voice. Herington and Gundlach (5) in a recent study of auditory sensitivity in the guinea pig find that their results are approximately equivalent to those obtained by Wever. None of the studies cited, however, have investigated the range of

audible tones or sounds. It is possible that the guinea pigs were responding to stimuli beyond the limens for rats. In general, the trend of the differences tends to show that guinea pigs are more easily distracted than rats and that they respond to unaccustomed stimuli by "freezing," a type of behavior disturbance not found at all in the animals of Experiment I.

It may be argued that some of the differences brought out in the preceding discussion are due to the differential maturation rates of the two groups of rodents. Figures 6 and 7 show the time at which certain characteristic types of activity appear in these closely

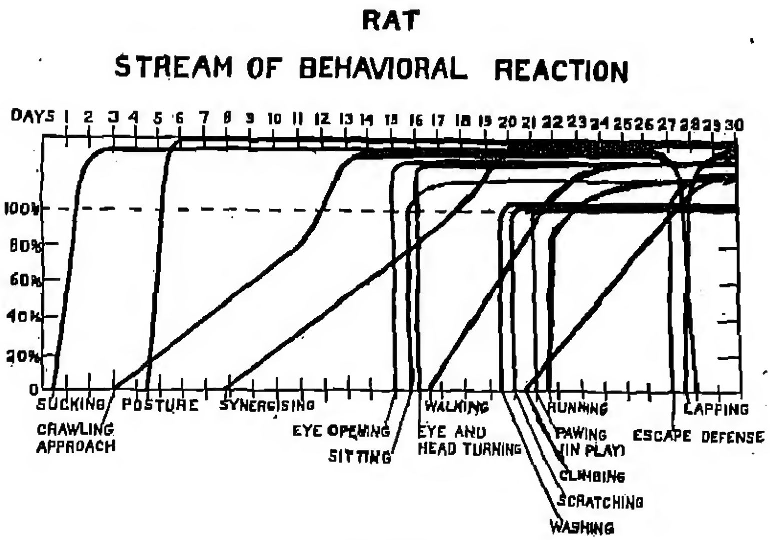

FIGURE 6

SHOWING THE TIME AFTER BIRTH WHEN DIFFERENT ELEMENTS OF A RAT'S BEHAVIOR MAKE THEIR APPEARANCE

Activities which come in gradually are indicated by a sloping line. (From F. Tilney)

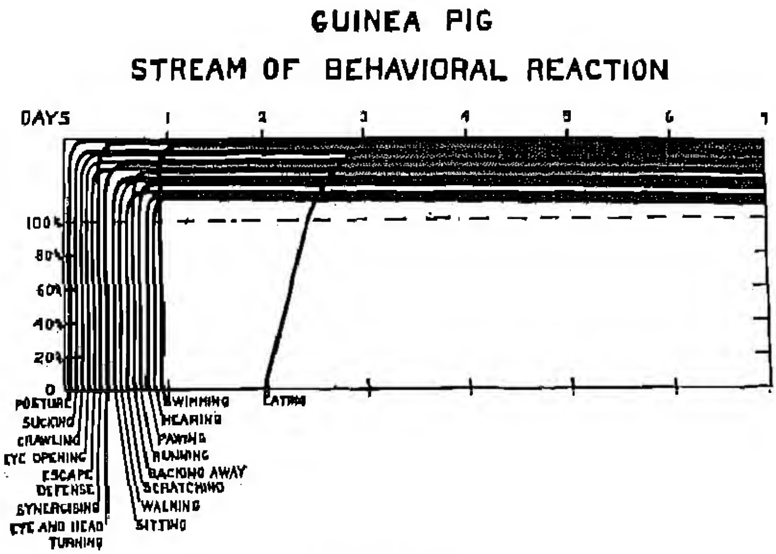

FIGURE 7

SHOWING THE TIME AFTER BIRTH WHEN DIFFERENT ELEMENTS OF A GUINEA PIG'S BEHAVIOR MAKE THEIR APPEARANCE
Activities which come in gradually are indicated by a sloping line.
(From F. Tilney)

related animals. The figures are drawn from the very careful work of Dr. Frederick Tilney, of the Neurological Institute, New York City. It will be seen that guinea pigs are quite mature at birth or very shortly thereafter whereas rats require some time before arriving at an equivalent stage of development. However, an attempt was made in the present experiment to select animals which were at approximately the same level of maturation. This, as may be seen in Figure 5, was accomplished by considering as variables to be equated the relation of age to weight and to the point of sexual maturity. It is not contended

here that the equation of the two groups is perfect but it is merely the best that can be done considering the absence of complete growth curves for the animals. It seems unlikely, therefore, that differences in behavior could have been due in any way to differences in the ages of the types tested despite the fact that the guinea pigs did average older than the rats when they came to Step II. Even at the age at which the guinea pigs were when they reached Step II, they had not as yet completed their growth in terms of age-weight relations and were approximately at the same part of the curve as were the rats. This can be seen from inspection of Figure 5.

Higher Mammalian Forms

As was mentioned in the introduction to the present study, research using the same apparatus has already been published by Shuey (13) on kittens and the results of the work with rhesus monkeys by Fjeld are to appear shortly in this series. Although the detailed comparison of various indices of learning for species differing widely in sensory equipment may not be highly significant, the comparison of limits of learning reached is certainly of great interest in comparative psychology. Of the mammalian forms tested thus far in this laboratory, the rodents have attained the lowest limits (one step for the guinea pigs and two for the rats). Kittens reached Step VII while monkeys extended the limit to Step XXII. These results, taken together, indicate the possibility of establishing differential levels of intelligence among mammalian forms when tested on identical tasks.

VII. SUMMARY

1. The limits of learning were determined in the Jenkins problem box, which provides tasks of increasing complexity without involving a different type of response, for two groups of animals, one containing 35 white rats and the other 30 guinea pigs.

2. The limit for rats was found to be the second step of the basic problem and that for guinea pigs to be the first step when the norm of mastery was 9 perfect trials in a sequence of 10. The same relative difference holds when the data are computed on the basis of a lower norm, i.e., 4 perfect trials in a sequence of 5.

3. The scores were extremely variable, the scatter being slightly wider in the case of the guinea pigs. A high percentage of the variability was due to the influence of a very few atypical animals in each group.

4. Although the guinea pigs were not able to master Step II, they succeeded in learning Step I in fewer trials and errors, and in less time than the rats.

5. The guinea pigs were found to be more sensitive to extraneous stimuli, particularly auditory, than were the rats.

6. The limits for rodents are extremely low as compared with those for kittens (Step VII) and for rhesus monkeys (Step XXII) on similar tasks.

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LES LIMITES DE L'APTITUDE À APPRENDRE CHEZ LE RAT BLANC ET LE COCHON D'INDE

(Résumé)

On a fait l'expérience dans le but de déterminer les limites de l'apprentissage chez deux groupes de rongeurs dans des tâches dont on a pu augmenter la complexité sans altération du type de réponse requise pour la résolution. Les sujets ont été 35 rats blancs mâles, pesant de 80 à 100 grammes, et 30 cochons d'Inde mâles, pesant de 380 à 400 grammes. L'appareil, la Boîte à Problèmes de Jenkins, se compose d'une boîte d'entrée et de deux cages circulaires concentriques, dont la plus petite contient le stimulant. Enfoncées au niveau du plancher entre les deux cages circulaires sont trois plaques, d'un diamètre de 15 centimètres, espacées de sorte qu'il reste 15 centimètres de chaque côté et que leurs centres sont les centres de trois des quatre quadrants qui composent le plancher de la plus grande cage. Le procédé pour les deux types de rongeurs a été identique sauf en tant que l'équation des groupes a nécessité la variation des aliments servant de stimulants, etc. Les tâches données aux sujets se sont composées d'apprendre à déprimer une ou plus de ces plaques dans l'ordre de succession donné par l'experimentateur. L'ordre des diverses tâches a été premièrement, la dépression de la plaque à droite (Etape I), ensuite la dépression des plaques à droite et par derrière (Etape II), et enfin, la dépression des plaques à droite, par derrière, et à gauche (Etape III). Aussitôt que l'animal était arrivé à la norme de maîtrise de 9 épreuves parfaites sur une succession de 10 épreuves sur une étape, on l'a fait passer à l'étape supérieure. Si un sujet n'a pas réussi à apprendre dans 700 épreuves, on l'a éliminé et l'on a noté qu'il est arrivé à sa limite. On a défini une épreuve parfaite comme celle où l'animal est allé directement à la plaque ou à la succession de plaques qu'il faut et s'est arrêté sur la dernière de la succession sans montrer aucune indication de passer aux plaques non comprises dans l'étape étant apprise.

La limite trouvée pour les rats a été la deuxième étape et celle pour les cochons d'Inde la première étape dans l'appareil employé, quand la norme de maîtrise a été 9 épreuves parfaites sur une succession de 10. La même différence relative entre les groupes se montre quand on compute les données sur la base d'une norme inférieure, c'est-à-dire, 4 épreuves parfaites sur 5 consécutives. Les deux groupes de rongeurs ont montré une variabilité extrême dans les épreuves de l'apprentissage, dans les erreurs et la durée ainsi que dans telles mesures de l'activité que le nombre de plaques dé-

primées et de quadrants traversés. Bien que les cochons d'Inde n'aient pu aprendre l'Etape II, ils ont réussi à apprendre l'Etape I en moins d'epreuves et moins de temps que les rats. On a noté diverses différences qualitatives, surtout dans la sensibilité des deux groupes aux stimuli extérieurs. Les limites pour les rongeurs ont été très inférieurs comparées à celles pour les chatons (Etape VII) et pour les singes rhésus (Etape XXII) sur des tâches semblables.

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DIE GRENZEN DER LERNFÄHIGKEIT BEI WEISSEN RATTEN UND MEERSCHWEINSCHEN

(Referat)

Das Ziel der Untersuchung war die Bestimmung der Grenzen der Lernfähigkeit bei zwei Gruppen von Nagetieren, an Aufgaben deren Kompliziertheit ohne Änderung der zur Lösung erforderlichen Reaktionsart gesteigert werden konnte. Als Versuchstiere dienten 35 männliche Albinoratten, die zwischen 80 und 100 Gramm wogen, und 30 männliche Meerschweinchen deren Gewicht sich zwischen 380 und 400 Gramm erstreckte. Das Apparat—der Aufgabekasten von Jenkins [Jenkins Problem Box]—besteht aus einem Eintrittskasten [entrance box] und zwei konzentrischen runden Käfigen von denen der kleinere die Anspornung [incentive] enhält. Mit dem Boden in gleicher Ebene liegend finden sich zwischen den zwei runden Käfigen drei Platten, 15 Zentimeter breit, die so angeordnet sind dass zu jeder Seite 15 Zentimeter übrig bleiben, so dass die Mittelpunkte dieser Platten die Mittelpunkte von drei der vier, den Boden des grösseren Käfigs bildenden Quadranten ausmachen. Das Verfahren war bei den beiden in Anspruch kommenden Arten der Nagetiere fast das gleiche. Nur die zur Gleichung der beiden Gruppen nötigen Unterschiede in Bezug auf das als Anspornung dienende Futter, u.s.w., wurden eingeführt. Die den Versuchstieren vorgelegten Aufgaben bestanden daraus, dass die Tiere lernen mussten, eine oder mehrere dieser Platten niederzudrücken, in Anordnungen [sequences], die von dem Versuchsleiter bestimmt worden waren. Die Reihenfolge der verschiedenen Aufgaben war folgende: Zuerst musste die rechts liegende Platte niedergedrückt werden (Stufe I), dann die rechts liegende und die hinten liegende Platte (Stufe II), und schliesslich die rechts liegende, die hinten liegende, und die links liegende Platte (Stufe III). Sobald ein Tier die Norm der perfekten Bemeisterung von 9 aus 10 aufeinanderfolgenden Proben auf einer Stufe erreicht hatte, wurde es auf die nächst höhere Stufe promoviert. Hatte ein Tier 700 Proben durchgemacht ohne zu lernen, so wurde es von der Versuchen ausgeschaltet. Die letzte bewältigte Stufe galt als die Grenze der Fähigkeit [limit of ability] des in Anspruch kommenden Tieres. Als eine Fehlerlos überstandene Probe [a perfect trial] galt eine Probe in der das Tier direkt auf die richtige Platte oder auf die richtigen Platten in der richtigen Reihenfolge zuging und auf der letzten Platte der Serie innehielt, ohne die geringste Neigung zu erweisen, zu anderen Platten hinzugehen, die nicht auf der zu bemesternden Stufe lagen.

Die für Ratten ermittelte Grenze [limit] war die zweite Stufe und die für Meerschweinchen ermittelte die erste Stufe in dem verwendeten Apparat, wobei die Bemeisterungsnorm [norm of mastery] die richtige Ausführung

von 9 und 10 aufeinanderfolgenden Proben betrug. Es bestehen relative die selben Unterschiede, wenn man die Befunde auf Basis einer niedrigeren Norm—4 aus 5 aufeinanderfolgenden Proben—berechnet. Beide Gruppen von Nagetieren erwiesen eine starke Variabilität in Bezug auf die Zahl der zur Bemeisterung nötigen Versuche, Zahl der Fehler, und Zeitverwand. Diese Unbeständigkeit [variability] zeigte sich auch in Bezug auf Masstaben der Lebhaftigkeit [activity], wie zum Beispiel die Zahl der niedergedrückten Platten und die der druchkreuzten Quadranten. Obwohl die Meerschweinchen die Stufe II zu bemeistern nicht im Stande waren, gelang es ihnen jedoch, die Stufe I in wenigeren Versuchen und mit geringerem Zeitverwand, als die Ratten, zu erlernen. Es zeigten sich auch verschiedene qualitative Unterschiede, besonders in Bezug auf die relative Empfindlichkeit der beiden Gruppen äusserlichen Reizen gegenüber. Die ermittelten Grenzen der Fähigkeit der Nagetiere erwiesen sich im Vergleich mit den an Kätzchen und an Macacus rhesus Affen mit ähnlichen Aufgaben ermittelten als sehr niedrig. (Kätzchen haben Stufe VII und Macacus Affen Stufe XXII erreicht.)

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THE LIMITS OF LEARNING ABILITY IN RHESUS MONKEYS*[1]

From the Animal Laboratory of the Department of Psychology, Columbia University

By

HARRIETT ANDERSON FJELD

*Accepted for publication by C. J. Warden of the Editorial Board and received in the Editorial Office, March 2, 1934.

[1]This report covers one major topic in a project on Motivation and Intelligence in the Rhesus Monkey (under the general direction of Professor C. J. Warden), supported by the Council of Research in the Social Sciences of Columbia University.

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INTRODUCTION

Many fascinating anecdotal accounts of the behavior and accomplishments of primates bespeak the interest with which man observed these animals long before laboratory methods of study had come into use. In addition to their purely literary and entertainment value, these stories have to some extent suggested problems for laboratory solution. They have raised questions as to the intelligence and learning ability of primates as well as to their emotional and social life. Problems related to learning ability of the smaller monkeys have been attacked from a variety of angles since the turn of the century. These investigations will be briefly summarized here. However, studies of imitation and delayed reaction will not be touched upon.

PROBLEM-BOX EXPERIMENTS

Thorndike, doubting much of the current interpretation of animal behavior, carried out a series of pioneer experiments, using first cats and dogs (29) and later monkeys (30) in a variety of problem-box situations. His primary interest was to determine how the animals learned, i.e., whether they learned by "trial and accidental success," by imitation or by the use of ideas. He was to a lesser extent interested in what they learned and how rapidly they learned it. For his primate subjects, he obtained three young cebus monkeys. Of the thirty-five different contrivances which he used, twenty-five were of the problem-box

type, eight were mechanisms so arranged that by certain manipulations food was thrown down a chute into the cage, and two were drawing-in devices. In the following summary of Thorndike's results, the general type of apparatus used is indicated in the column headed "Problem" by B, C, and D, meaning problem box, chute, and drawing-in device respectively.

Problems (in order of presentation)	Subjects tested	Subjects failed	Subjects succeeded
1 B String	1		1
2 B Bolt	1	1	
3 B Single bar	1		1
4 B Double bar	1		1
5 B Hook, left side	1		1
6 B Hook, right side	1		1
7 B Two hooks	1		1
8 B String and nail	1	1	
9 D String box	1		1
10 D String box	1		1
11 B Wood plug	1	1	
12 B Wood plug, hook and bar	1		1
13 B Nail plug	1, 2, 3		1, 2, 3
14 B Plug at side	1, 2, 3	1, 2, 3	
15 B Bar inside	1, 2, 3	1, 3	2
16 B Bar outside	1, 2, 3		1, 2, 3
17 B Push bar	1		1
18 B Hook at left	2, 3		2, 3
19 B Nail plug, hook and bar	1, 2, 3		1, 2, 3
20 B Catch at back	1, 2		1, 2
21 B Bolt, side plug and knob	1, 2, 3	1, 2, 3	
22 B Bolt on right	1, 3	1, 3	
23 B Ring at back	1, 3		1, 3
24 C Push bar	1, 3	1, 3	
25 B Wire wound three times around screw	1, 3	3	1
26 B Push bar	1, 3	1	3
27 C Turn bar 270°	1, 3	3	1
28 B Side plug	1, 3		1, 3
29 C Turn bar 2½ revolutions	1, 3	3	1
30 C Nail plug	1, 3	1, 3	
31 B Lever	1, 3	1, 3	
32 C Ring	1, 3	1	3
33 C Hook	3	3	
34 C String loop	1	1	
35 C Wire loop	1, 3	3	1

This summary merely shows whether the subject failed or succeeded. Number of trials is not given since there was no uniformity of procedure. In a few cases repeated trials were given even though the animal succeeded on the first trial, while in many instances only one trial was given regardless of success or failure. The time of the failure trials ranged from five to sixty minutes, the usual time being either five or ten minutes. In no cases were more than four failure trials recorded. The results indicated distinct superiority of the monkeys over the cats and dogs which had previously been tested on many similar devices by the same experimenter. Thorndike concluded however that, although there were steep drops in some of the learning curves and almost immediate learning in certain cases, learning was essentially of the trial-and-error type, there was no indication of reasoning and not sufficient evidence to prove the existence of ideas.

Following up Thorndike's work, Kinnaman (15) made use of a variety of problem-box, chute, and string-box situations to test two Macacus rhesus monkeys, one male and one female. However, most of the data were obtained with the male since the female worked very poorly much of the time. As in nearly all of Thorndike's box experiments with the monkeys, the food was inside the box and the animals were on the outside. The various devices used by Kinnaman were:

A. Simple fastenings for box

1 Thumb button (30-degree turn)
2 Hook (vertical)
3 T-latch
4 Bolt

5 String (wound around screw)
6 Plug
7 Lift-latch
8 Push-bar
9 Bear-down latch
10 String and bolt
11 String and ring
12 Horizontal hook
13 Lock and key

B. Chute apparatus
14 String below
15 String at back
16 Windlass

C. 17 Pull-in box with string

D. Second positions of
18 Button
19 Vertical hook
20 T-latch
21 Bolt
22 String and nail
23 Plug
24 Lift-latch
25 Push-bar
26 Bear-down latch

E. Groups of fastenings
27 Two buttons
28 Two bolts
29 Button and bolt
30 Two buttons and one bolt
31 Two buttons and two bolts
32 Two plugs
33 Three plugs, two buttons and two bolts

F. Combination locks
1 Right plug, left plug, bolt, button, and hook in order
2 Bear-down lever at left, push-in bar at right, lift-up latch in front, and pull-out string behind in given order

Small amounts of either rice, bread, banana, or apple were used as incentives. The length of the trials ranged from 1 to 672 seconds, depending upon the time neces-

sary to solve the problem. No failures appear in the data tabulated.

The results include a time record for the male for thirty trials on each of the seventeen devices listed under A and B, a comparison of records for first and second positions of identical devices, time and error records for the two subjects on the combination locks, and a number of learning curves. The composite time curve for the male, combining his performances on the seventeen simple problems, shows a steep drop at the first, while the minimum time is practically reached by the tenth trial. The time taken for the various problems ranges from 1 to 672 seconds on first trials and from 1 to 10 seconds on tenth trials. On the average the time necessary for learning second positions of identical locks was about half that for first positions. The curve for groups of fastenings, the units of which had already been learned, shows the initial drop in the learning curve to be less marked than in the curve for the single fastenings. However, the minimum time for the groups of fastenings was reached on the sixth instead of the tenth trial.

In training his subjects on the combination locks, Kinnaman used a norm of ten errorless trials in succession. The male required 253 trials and the female 80 trials to reach this criterion with the first set of combination locks. Each animal was given 250 on the second combination but neither reached the standard of ten errorless trials. Kinnaman also tested twelve human adults and five children with the same two sets of combination locks. While learning was more rapid

on the part of the human subjects, he observed the method of all subjects to be essentially that of trial and error.

Kohts (18, 19) used a single female rhesus monkey in a series of experiments designed to study what she called "labour processes." She employed problem-box situations involving the following general types of devices:

1 Hooks
2 Latches
3 Turning locks (eccentric handle)
4 Sliding bolts
5 Turning locks (center handle)
6 Chain and knob bolts
7 Hinged strap with eye and locking bolt
8 Inside lock opened by key
9 Padlocks
10 Tape with unwindings and knots
11 Overhanging and sliding doors

The number of problems was increased to 93 by introducing such variations as differences in (1) ease of operation, (2) external appearance (color, form, size, etc.), (3) position (horizontal, vertical, inclined, right or left side, top, bottom, or center), (4) number of similar devices presented, (5) combinations of different types of devices.

Apparently food was always used as an incentive. Degree of hunger varied, however, and especially attractive bits of food were used when the animal was satiated. Additional forms of incentive, such as freedom from confinement and swinging the animal, were used in some cases.

Of the 60 single devices and 33 groups of fastenings,

the subject failed completely with only two, the tightly inserted simple hook and a padlock locked by an unattached key. Aid was given by the experimenter in unlocking the first hook, the first bolt (having a novel method of unlocking), one other type of bolt, five devices which required considerable force, a chain and knob, a padlock, and seven groups containing new units which, being out of sight, were not discovered by the monkey.

Kohts emphasized the great number of random movements exhibited by her subject; also the apparently blind solutions of the problems as shown by frequent pulling at the door before unlocking and by repeated locking and unlocking of a single device during a given trial. She concluded that the monkey has no understanding of what is necessary to be done and is unable to foresee its consequences.

A number of experimenters have used various forms of problem-box tests as somewhat incidental parts of more extensive studies. Shepherd (26) trained three rhesus monkeys on a simple problem box, as a preliminary to later discrimination experiments. The monkeys took 95, 102, and 64 trials respectively to learn to unfasten a single button door. The fastening was on the inside of the box, making it necessary for the monkey to put his hand through a hole at the side of the door in order to turn the button. The food was out of sight unless the animal went to the extreme side. However, the account indicates that the monkeys were persistent in their errors to obtain the food.

A young rhesus monkey, tested by Hobhouse (13)

on a box experiment, at first failed to release a bolt fastened by a hook, but later appeared to learn quite suddenly after a first success.

Buytendijk (3) trained his cercopithecus monkey to open a box by pushing up a lever. When the habit was well established, he introduced a number of difficulties. He first fastened to the lever a cord with a heavy piece of wood attached. When the block was not too heavy, the monkey succeeded without difficulty in lifting the block and placing it on the table, thus making it possible to open the door. Buytendijk then fastened the end of the cord with a hook and eyelet. Contrary to Hobhouse's results, after several trials the animal still made no attempt to detach the hook. Next the lever was fixed to push down instead of up. The monkey learned to manipulate this after five trials. An obstacle in the form of a block was then placed under the lever but the animal never learned to remove the block. The block was replaced by a flowerpot which the monkey had previously learned to overturn in order to secure food. However, she failed to remove the pot until food was placed under it.

Nellmann and Trendelenburg (23) found that their smaller monkeys learned only by trial and error to open the lid of a box fastened by bolts. They failed completely when the bolts were so arranged that the animals had to push them away from themselves. The Pavian monkey was unable to learn the combination bolts, while the Java and rhesus monkeys both succeeded after training.

Drescher and Trendelenburg (4) reported that their

Java monkey and Pavian monkey failed to unfasten a simple lock on a box although given many repetitions. The rhesus learned to open it and the gibbon was successful even with two locks.

Tool Experiments

The ability of monkeys compared to that of anthropoids in the use of tools or instruments has been a subject of considerable interest. The small monkeys succeed readily with the drawing-in problems when a string or stick is directly attached to the food but usually have been found unsuccessful in using a rake unless properly placed back of the food (3, 4, 20, 23, 35). However, Hobhouse (13) reported that his rhesus monkey did learn to rake in food with a stick. Klüver's (17) cebus monkey apparently was very proficient in using a variety of objects to rake in food. Bierens de Haan (2) found that one of his nine subjects, a Cebus monkey, was able to use a stick either as a rake or as a beating tool. She succeeded even when the object used as a rake was not visible at the moment when needed.

The smaller monkeys usually fail in the tube experiment, when it is necessary to push food out of a tube with a stick (3, 13, 23, 35). Drescher and Trendelenburg (4) concluded from their experiments that only higher monkeys can use an instrument or tool in motion away from themselves. The results of Guillaume and Meyerson (8, 9) are in line with this as their smaller monkeys were unsuccessful in the detour or roundabout experiments. They set up a variety of situations

in which it was necessary for the subject to use a stick or his finger to push food away from himself or to one side in order to obtain it. Furthermore, Klüver (17) found the detour-beam problem to be one of the few in which his Cebus monkey failed. However, Verlaine and Gallis (31) were able to teach their Macacus sinicus to push food out of a small glass tube (6 cm. long) and this animal later succeeded in using a variety of other objects to obtain the food when the stick was not available. This same monkey, in a set-up similar to that of Guillaume and Meyerson, was able to obtain food by pushing it at an angle of 90 degrees but failed when it was necessary to push it directly away from himself. However, Verlaine and Gallis believed this failure was due not to any mental inability but rather to the fact that it is particularly difficult for a monkey to make this reaching-out movement.

Earlier experimenters reported slight success on the part of the small monkeys in box-stacking problems. Hobhouse (13) was able to teach his rhesus monkey to place a stool or box to climb on. Three rhesus monkeys used by Shepherd (26) paid no attention to a box left near suspended food. Yerkes' (35) Pithicus irus monkey learned to place the larger of two boxes on end under the fruit and tried to drag up a smaller box but failed. Yerkes believed he would have succeeded with sufficient trials. Nellmann and Trendelenburg (23) found that their rhesus gave some indication of ability to solve the box problem by pushing the box in the direction of the goal, climbing on it, and jumping. With further training he might have succeeded.

Much more striking were the results obtained by Bierens de Haan (2) with his Cebus monkey. The subject was first given one box which she immediately tried to push into place, but the box was too heavy. When given a lighter box, she succeeded after a few trials in placing the box on end and obtaining the fruit. She was then given two boxes, one placed under the fruit too low for her to reach and a second box left near by. After a few unsuccessful attempts to use the smaller box as a beating tool, she placed it on top of the larger box but it fell off and she was unsuccessful until the fourth trial. The following day she was given a larger box which she turned on end and succeeded in obtaining the fruit. In the next experiment two boxes were used, neither one being placed under the fruit. Bierens de Haan believed the monkey understood at once what to do although she was sometimes unsuccessful. Then three boxes were used, two being placed under the food and the third left to be stacked. She succeeded immediately. When one box was placed under the food and two left to be stacked she was successful in principle but failed to obtain the food because of lack of skill. However, when one of the boxes was replaced by a tin can she was successful. She later succeeded when three boxes were placed in three different corners and even when one of the boxes was hidden. Bierens de Haan explained the discrepancy of his results as compared to those of other experimenters as due to possible superiority of the subject, to the greater simplicity of his experimental set-up, and to better control of the living-conditions of his

animal. In previous experiments the subject frequently had been presented with tasks of too great difficulty and with too great variety at once, instead of using one type of tool and gradually increasing the difficulty. He also believed that his plan of keeping the animals separated as to sex was advantageous for increasing motivation.

Verlaine and Gallis (31) reported an experiment in which their Macacus sinicus monkey learned to place a variety of boxes to climb on, one of which he rolled into place and set on end.

Klüver (17) carried out over 200 experiments with an adult Cebus monkey, which showed great facility in the use of tools, her performance comparing quite favorably with that of the anthropoid apes. A younger Cebus monkey showed a distinct tendency to use objects as tools but was much less efficient. This led Klüver to suggest that the ready and efficient use of tools may grow out of very "diffuse" and general reactions such as he observed in the younger monkey. His seven Java monkeys, two spider monkeys, two squirrel monkeys, and one lemur failed to use objects as tools in the problems which he presented to them. His own results together with the reports of other experimenters led him to the tentative hypothesis that complex forms of tool behavior may be peculiar to the Cebus monkey.

However, Verlaine and Gallis (31) obtained very good results with a Macacus sinicus monkey not only in the tube experiment but also in a box situation in which it was necessary for the animal to use a tool

to release the catch. The monkey, after having learned to open the box with a nail by being put through the act a number of times, was then able of itself to make use of a great variety of objects in place of the nail. He even broke off and used branches of a dried plant as the necessary tool. He bent the fiber of a street broom into a position where he could use it for opening the box.

As the reports of Bierens de Haan, Verlaine and Gallis, and Klüver have shown, the gap between the lower monkeys and the great apes in their ability to use tools is not so great as had been supposed. On the contrary, there appears to be considerable overlapping in this function.

Other Manipulation Experiments

The smaller monkeys usually succeed in attempting to open a hand they have seen close over food (1), in overturning flower pots under which food or some other incentive has been placed (1, 3, 4, 23, 31), in using a string to draw in a box or bucket into which food has been dropped (1, 4, 9, 17, 20, 23, 26, 35), and in pulling in a string to obtain food which has been placed out of sight on a high shelf (1, 4, 23). They are much less successful in finding food dropped into a pocket (1, 23), in opening a drawer (1, 13), or in rotating discs and levers (4, 9, 23) to obtain food. They are fairly successful in unwinding a chain wrapped around a stake or table leg (3, 13, 22). Guillaume and Meyerson (9) found their smaller monkeys distinctly inferior to the anthropoids in a variety of

string experiments requiring indirect pulling. However, Nellman and Trendelenburg's (23) monkeys succeeded readily in pulling in food at an angle by means of a string. Verlaine and Gallis (31) reported that both their Macacus sinicus and Macacus rhesus succeeded immediately in obtaining food fastened in the middle of a string secured at the far end and brought into the cage at an angle so that it was necessary by working through the bars to take the string from one end of the cage to the other. These monkeys succeeded whether the end of the string was placed inside or outside of the cage.

Non-Manipulation Experiments

Problems not involving manipulation have been used by a number of experimenters to study the ability of monkeys. Hamilton (11) devised an ingenious method of prolonging the variability phase of the learning period and thus afforded an excellent opportunity to study various types of behavior. Using his quadruple-choice apparatus he set up an insoluble problem situation in which the one soluble factor was that the positive alley in a given trial was never the same as in the preceding trial. His subjects included ten humans, five monkeys, sixteen dogs, five cats, and one horse. Each subject was given one hundred trials. Upon analyzing the data for types of behavior, he found that only human subjects manifested what he called the rational inference tendency. The unmodified searching tendency (irregular order) appeared most frequently in the defective man and next in the

monkeys. The tendency to use stereotyped modes of searching was most apparent in the monkey. The searching tendency modified by reappearing motor impulses was greater in adult monkeys than in man but less than in dogs. The tendency toward perseveration of active motor impulses and of inhibitions appeared with increasing frequency as both the ontogenetic and the phylogenetic scales were descended.

Using the same general set-up several years later, Hamilton (10) tested twenty girls, one baboon, four monkeys (two Pithicus rhesus and two Pithicus irus), one mouse, five grey rats, four black rats, and six gophers. He found that the manner in which a subject varied his response seemed to depend more upon the individual than upon the species. However, the children showed the greatest tendency to react to the rule that the same alley was never the right alley in two successive trials, while the infrahuman primates came next.

In an attempt to study ideational behavior, Yerkes (35) employed a learning situation using the multiple-choice method with two monkeys (Pithicus rhesus and Pithicus irus) and one orang-utan. The problems set for the animals were (1) the first box at the left, (2) the second at the right, (3) alternately first at left and first at right, (4) the middle one, and (1*a*) the first at the right. Of the three problems presented to him, the orang-utan solved only problem 1, and that after more than twice as many trials as was necessary for the other subjects. He failed completely with problems 2 and 1*a*. The irus monkey learned prob-

lem 1 fairly satisfactorily in 134 trials and appeared to learn No. 2 in 1070 trials. However, he failed in the tests for the second problem. Of the three subjects, the rhesus made the best record. He learned problems 1, 2, and 3 in 70, 400, and 470 trials respectively. He failed in problem 4, but Yerkes thought this was probably due to disturbing environmental conditions. Although the orang-utan had a much poorer record than the rhesus and no better than the irus, Yerkes believed he was more intelligent than the smaller monkeys. Partly due to the sudden learning in problem 1 and partly due to certain types of behavior, Yerkes concluded that the orang-utan made use of ideas. The large number of trials in problem 1 and subsequent failures in the other problems were attributed to the inadequate use of ideas.

Buytendijk (3), using a multiple-choice set-up with eight drawers, trained a female Cercopithicus monkey on an alternation problem in which the correct response was going alternately to drawers 1 and 8. After the correct habit had been fairly well established, it began to disintegrate and the animal developed a position habit of always going to the left. Buytendijk stated that there was not sufficient punishment used to obtain a perfect performance.

Revesz (24) was unsuccessful in training a monkey to react to a specific box in a multiple-choice problem involving six boxes. After 17 trials the subject was able to select some box in the region of the correct one. After 45 trials it was still a matter of chance if he selected the exact box. Revesz found similar be-

havior in very young children. He also compared children and monkeys in ability to discover a system. Again a row of similar boxes was placed before the subject. In each succeeding trial the incentive object was to be found in the box next in line, beginning at one end and progressing to the other. While all of his human subjects over five years of age learned the system in from three to twelve trials, all four of the monkeys failed after an "enormous number" of trials even when the number of boxes was reduced to two. In view of Yerkes' results with his rhesus monkey, Revesz is inclined to believe his monkey might have succeeded in the simple alternation problem if given still more training.

Kuroda (20), using a multiple-choice apparatus similar to Yerkes', trained a Macacus cynomolgus monkey on a number of problems with little success.

Tellier (28) set up on insoluble problem similar to that used by Hamilton in which the correct box in a given trial was never the same as the correct box in the succeeding trial. She simplified the conditions by using merely a row of small boxes placed in front of the animal. In the first problem she used only three boxes. After 30 trials her rhesus monkey learned to respond correctly, i.e., to avoid the box in which food had last been found. The number of boxes was then increased to four and the monkey immediately made 10 perfect reactions out of 12. When the number was increased to ten, the animal made 23 correct responses out of 31, then 10 successive correct trials.

Tellier (28), using two rows of boxes, trained a

Macacus sinicus monkey to choose the box located second from the left in the front row. The animal learned after 159 trials and still succeeded when the spacing of the boxes was so varied that the correct box was sometimes toward the left and sometimes toward the right side of the series of boxes.

The double-alternation problem was studied by Gellermann (6, 7). He first worked with the temporal maze used by Hunter for raccoons. Two young rhesus monkeys, a male and a female, learned the problem in 80 and 315 trials respectively. Gellermann decided, however, that the maze was not a satisfactory type of apparatus for monkeys, and later used a box apparatus setting up a double-alternation problem of a series of eight responses, *RRLLRRLL*. All of the four rhesus monkeys used in this experiment learned the series, the criterion for learning being a norm of three perfect trials in succession. The monkeys were also able to extend the series to a longer one. In the double-alternation problem, Gellermann found that his monkeys ranked below man but above raccoons and rats.

Number Experiments

A few efforts have been made to study the ability of monkeys to count or to discriminate between different numbers of stimuli. Kinnaman (16) arranged an experiment designed to give number tests to his two rhesus monkeys. He placed twenty-one similar containers in a row and trained the subjects first to the fourth from the end. He then trained to the second,

fifth, first, ninth, eleventh, eighth, third, tenth, and seventh in the order given. The full series was carried out only with the male, the female being trained on no number above six. The subjects were given 270 trials on each problem. He concluded from his results that, with this apparatus, numbers from one to six and from one to three were recognized by the male and the female respectively.

Three rhesus monkeys were trained by Woodrow (34) to discriminate between different numbers of stimuli. One subject learned to differentiate between one and three, two and three, and three and four sounds, and with a low degree of reliability between four and five sounds but failed to discriminate between five and six. A second subject learned to distinguish between one and three, two and three, and three and four, but failed with four and five. Furthermore, it was necessary for this subject to relearn to discriminate between two and three when the interval between the first and last sounds was made the same. The third subject learned to discriminate between two and three sounds but later the habit disintegrated.

A Macacus cynomolgus monkey, trained by Kuroda (21) on a multiple-choice apparatus, was able after about 700 trials to react to aperture number one upon hearing one stroke of a bell and to aperture number two upon hearing two strokes. The habit broke down completely, however, when a third factor was added and the animal was required to react to one, two, or three.

Gallis (5) gave a preliminary report of an attempt

to discover whether monkeys can get the concept of numbers. His method was to train the animal to take a given number of bits of food and make no attempt to obtain more. For example, in training to the number three, if the monkey obtained three meal worms from one closed hand, he was not to attempt to open the hand next presented to him, but if he obtained only one or two the first time he would continue to open the hand presented until he had obtained the three and no more. Gallis stated that he tried to avoid giving his animals cues of any kind. He believed his two Macacus sinicus monkeys demonstrated their ability to get the concept of the numbers two and three.

Summary of Experiments

A perusal of the literature discloses many different methods, aims, and points of view. A great variety of problem-box situations has been used to test the intelligence of monkeys. Pioneer experiments by Thorndike (30) and later studies by Kinnaman (15) were made at an early period before laboratory technique had become highly refined as it is in the United States today. Consequently there was relatively little attention given to standardization of conditions. The work of Kohts (18, 19), though recent, showed little more attention to these factors. The number of subjects in each case was small, ranging from one to three. Nevertheless, these experimenters have made valuable contributions in the great variety of situations presented, in careful descriptions of behavior, and in theoretical discussions.

In large part the tool and other types of manipulation problems have been of a more or less exploratory nature, the experimenter presenting a variety of situations to the subject and recording whether or not the animal succeeded in solving the problem, and frequently giving valuable qualitative descriptions of behavior, but with little attempt to control the conditions. Most of these experimenters have been interested chiefly in the ability of the animals to comprehend the situations. Thus the experiments have not been primarily training situations. The work of Bierens de Haan is somewhat in contrast, being quite systematically carried out. He began with a very simple task and gradually built up a more complicated performance using the same general type of tools. Verlaine and Gallis also began by using a very simple situation and training the animal step by step until it became proficient in the desired task. Here the experimenters even went so far as to put the animal through the act and to give aid at difficult points by holding the arms in position, etc. After the fundamental performance was perfected, a number of test situations were presented to discover whether the animal would make a generalized use of tools. Bierens de Haan, as well as Verlaine and Gallis, points out that for the most part the experimenters have not adapted their tool set-ups to the monkeys. Klüver not only carried out a large number of experiments on a single subject and made careful behavior records, but gave more attention to controls. His appears to be the only study of the use of tools in the smaller monkeys in

which there has been an attempt to exclude the experimenter.

Coming to the non-manipulation problems, in the work of Hamilton and Yerkes, there were improvements over the early problem-box experiments in standardization of apparatus, method of handling, number and distribution of trials, but still no rigorous system of controls for all conditions. The studies of Buytendijk, Revesz, and Tellier were less extensive and gave little indication of controls used. In the work of Gellermann was found a much more highly standardized set-up with the experimenter excluded and well-controlled laboratory conditions. The preliminary period, including taming, is especially important and this was particularly well controlled by Gellermann. However, feeding was not sufficiently standardized and he stated that occasionally the monkeys were overfed and refused to work.

A review of the literature indicates the extreme necessity for carefully controlled conditions in experiments with monkeys because of their great distractibility and the difficulty of keeping them properly motivated. Some factors of primary importance to be considered are: age, past experience, diet (kind and amount of food, and distribution of feeding periods), hunger (the relation of the experimental period to the feeding periods), method of handling, method of introduction to the experimental situation (taming and preliminary trials), the immediate conditions of the experiment (incentives, lighting, exclusion of other animals and of the experimenter, elimination of dis-

tracting stimuli not directly connected with the problem), number and distribution of trials, and the length of each trial. All of these factors have been considered in the present study and with a few exceptions, as will be indicated later, were well controlled.

PRESENT EXPERIMENT

The chief problem of the present study was to determine the limits of learning in a group of young rhesus monkeys. The simple reaction of depressing a plate or disc in the floor of a problem box was used. Starting with a single plate, the complexity of the response was gradually increased by adding plates one at a time until the series was extended beyond the animal's ability to learn. An attempt has been made to analyze the behavior of the animals during the learning process, to indicate any trends which appear, and to discover whether these trends are peculiar to the individual or common to the group.

This experiment differs considerably from preceding studies with monkeys. Some experimenters have increased the difficulty of their problems by increasing the number of devices to be manipulated. However, the devices have usually differed in kind as well as increased in number, and rarely has there been a set order of manipulation. In a few instances series of similar devices have been used, but with no thoroughgoing attempt to find the limits of the series.

The study, however, is similar to the work done by Shuey (27) with kittens, and that done by Riess (25) with rodents. A similar Jenkins problem box, but

having larger dimensions, was used. As has been pointed out by Jenkins (14), Shuey, and Riess, this apparatus, making use of a simple reaction system common to a large number of phyla, makes possible comparative studies of a great variety of animals. A part of the problem, then, has been to compare the performance of the monkeys with that of the kittens and of the rodents and to evaluate that comparison.

II

METHOD AND PROCEDURE

The present experiment was in progress from October 16, 1930, to September 15, 1932. This study was a part of a larger project, and Mr. T. A. Jackson worked with the author in standardizing some phases of the general procedure. Mr. Jackson also took the data for a period of about three months during a necessary leave of absence on the part of the writer.

The experimental room was in a secluded part of the laboratory. Its one large window faced the quiet side of the campus and was equipped with a dark shade which effectively shut out the light. Each of its two doorways was closed by a regular door and a sound-proof door. One entrance was permanently closed up, while the other led into the room where the monkeys were kept. This was a light, airy room with three large windows.

The cages in which the monkeys were kept were constructed of sheet iron with a door which formed the entire front, and a window at the back, both covered with heavy wire mesh. Floors of removable wire grates over a metal pan filled with wood shavings facilitated efforts to keep the living-quarters sanitary. The individual cages were 35½ inches deep, 27½ inches wide, and 30¼ inches high. They were arranged in two rows of two tiers each, facing each other. The runway thus formed between the cages was enclosed with heavy wire mesh fastened to a steel frame (see Figure 1).

Apparatus

The apparatus used was a large model of the Jenkins problem box (14). An illustration of the problem apparatus is shown in Figures 1 and 2. The main part of the apparatus consisted of three compartments: a circular reaction compartment, 7 feet in diameter and 28 inches in height; an incentive compartment, 28 inches in diameter and 28 inches in height, located in the center of the reaction compartment; and an entrance compartment, 27 inches long by 14 inches wide by 14 inches high. The entire apparatus was constructed of a steel framework and heavy wire mesh set on a solid maple base elevated 22 inches above the floor. The base was painted with battleship gray and the metal work with aluminum paint.

There were three reaction plates located in the floor of the reaction compartment, as shown in Figure 3. These plates were of the natural maple color and inlaid with copper strips which were wired for shock. They were set into the floor of the box so that the tops of the plates were flush with the floor. Underneath they were equipped with square metal posts which worked up and down freely through sleeves piercing the floor of the box. By means of an adjustable spring, each plate was held up to the level of the floor but could be depressed approximately ⅛ inch by a light pressure. For this experiment the plates were adjusted to weights of from 75 to 100 grams.

Three doors were of primary importance for experimental purposes. The entire outer end of the

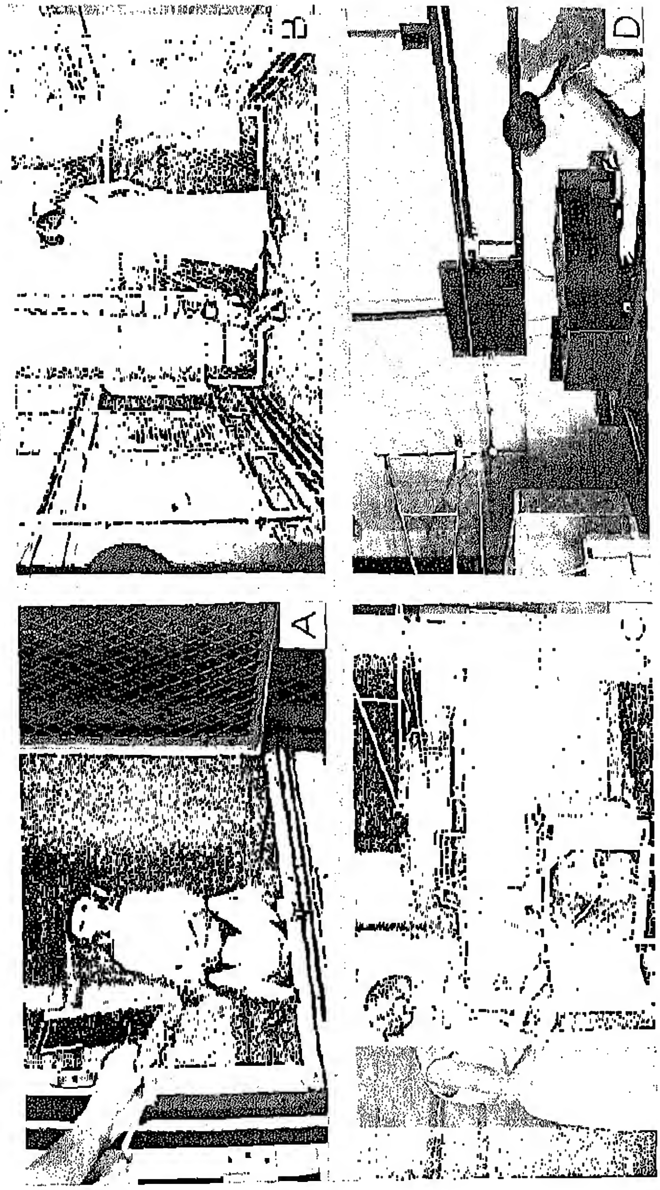

FIGURE 1

Some of the Conditions of Testing (Subject X—"Bright Girl")

A—leaving the cage; *B*—starting for the experimental room; *C*—in the entrance compartment; *D*—taking data at the control table.

(Photographs by E. I. Fjeld.)

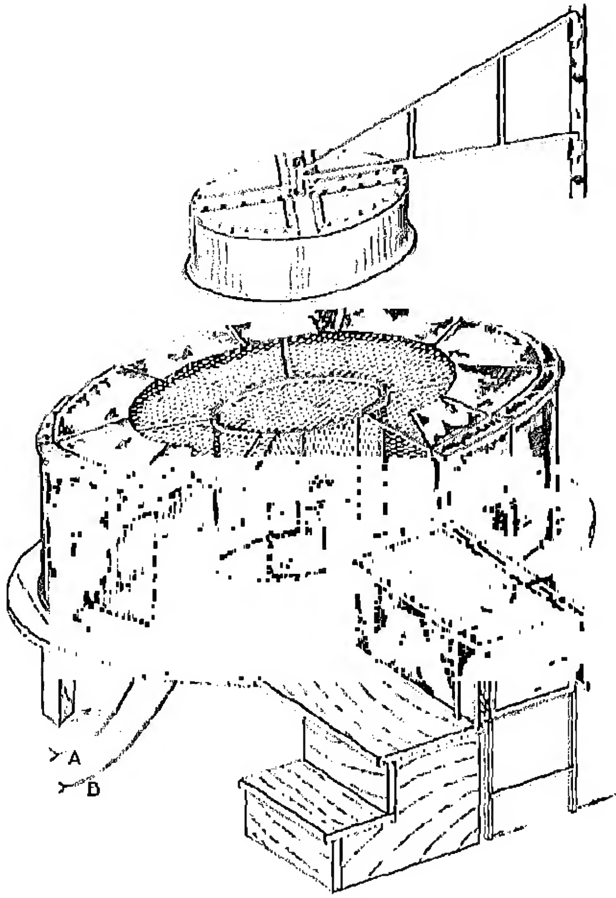

FIGURE 2
Jenkins Problem Box

Parts of the one-way screen and cage have been removed in order to make the interior of the apparatus more visible. The three plates in the floor are wired for shock, the current being supplied through *A* from the Jenkins Stimulation Apparatus (not shown). The electrical system (not shown) operates through *B* to open the door of the incentive cage when a given problem has been solved. The cord leading up from the door of the entrance compartment runs over a pulley and is operated by the experimenter some distance away. The large central illumination chamber is shown pushed back from the apparatus. By courtesy of Professor C. J. Warden.

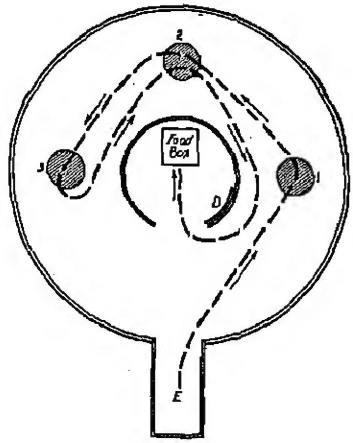

FIGURE 3

FLOOR PLAN OF JENKINS PROBLEM BOX

The broken line indicates a perfect response in Step IV. The animal starting at *E* is required to step on the plates in the order 1, 2, 3 and reverse to 2, to open the door, *D*, and obtain access to the food. By courtesy of Professor C. J. Warden.

entrance compartment consisted of a hinged metal door (outer door) 14 inches by 14 inches. A vertical sliding door (entrance door) closed off the entrance compartment from the reaction compartment. This door was constructed of bakelite and covered with aluminum paint to match the metal part of the apparatus. The door into the incentive compartment (inner door), like the walls of the compartment, consisted of a steel frame and wire mesh. It was located directly in front of the entrance door and was 14 inches high by 9½ inches wide. It was held shut by an electromagnetic device and was constructed in such a way that when released it opened by force of gravity

and came to rest by its own inertia. This construction made its operation relatively noiseless.

The large circular cage was lighted by four 25-watt and eight 40-watt bulbs set in a large reflector 38 inches in diameter by 13¼ inches deep. The reflector was larger in diameter than the inner cage and the lights were so arranged as to give a very uniform light. This eliminated shadows which might have been cast by the framework and walls of the cage. The light was diffused through sheets of opal and plate glass into the apparatus below. The light fixture was attached to the wall of the room by a movable arm and could be swung back away from the apparatus when desired. The entrance compartment was lighted by a 10-watt bulb set in an ordinary reading-lamp reflector closed at the bottom with a sheet of opal glass.

The entire apparatus, with the exception of the top of the entrance compartment and the top center of the main cage where the light was located, was covered with a fine screen wire painted white. Under experimental conditions of a darkened room and lighted apparatus, this formed a one-way light screen which eliminated visual cues that might otherwise have been given by the experimenter.

The experimenter's control table was situated at the right and in front of the problem apparatus, the experimenter's chair being approximately 7½ feet from the front of the box (Figure 1). On the control table were located the switch board and the relays which controlled the operation of the inner door. A dia-

gram of the wiring system is shown by Warden, Jenkins, and Warner (33, Chapter IX).

The operation of the apparatus has been described in detail by Jenkins (14) and only the major functions will be reviewed here. As has already been indicated, the inner door was held shut by an electromagnetic device. The wiring was so arranged that when the proper reaction plate or plates in the floor of the box were depressed the circuit through the magnet was broken and the door released. It was possible to set the switch board for a variety of combinations of plate reactions, control being mediated through a system of relays. For example, in one setting the door was released by the depression of any plate; in another it was released by the depression of a certain plate; in others it was released by the depression of the plates in any predetermined sequence.

There were three small signal lights on the switch board, one connected with each plate in such a way that when the plate was depressed the light would be extinguished but would reappear when the plate sprang back into position. These lights aided the experimenter in taking accurate records and indicated that the electric control system was operating properly.

A 10-watt pilot light located on the control table was enclosed by a black box with a tiny slit which was covered with a small sheet of paper. Thus only sufficient light was emitted to allow the experimenter to take the necessary records. The control table also contained all of the necessary switches for the lights, for

applying shock, and for releasing the inner door when desired.

The inner door of the entrance compartment was operated by means of a cord which ran through a series of pulleys to the control table. The door of the food cage could also be released manually when desired. Such noises as could not be avoided in operating the doors did not seem to disturb the animals. Nevertheless, a 16-inch electric fan was run constantly at medium speed during the test period as an additional precaution.

Subjects

A group of seventeen young Macaques rhesus monkeys were used in the regular experiment. These subjects probably ranged from 24 to 31 months in age. They were obtained from a local dealer and were brought into the laboratory almost directly upon importation.

Protocols

Monkey A. Male. Weight, 86 ounces.[3] Limit, 22 steps.

The general physical condition of this monkey was excellent. He tamed readily but was always aggressive and never gentle or docile. He was quick to show anger toward other members of the colony and finally became so pugnacious that he was not allowed to run with them during the daily exercise period. He was extremely active and frolicsome. His behavior in the experimental situation was characterized at first by much romping and playing; however, as the problems became more complicated he worked very consistently and rapidly.

Monkey B. Male. Weight, 68 ounces. Limit, 12 steps.

This monkey's general physical condition was good throughout,

[3]The weights given for all of the subjects were obtained during the period of *adjustment shortly after the monkeys arrived in the laboratory.*

He appeared to be rather delicate at first but later developed into one of the finest specimens of the group. He tamed readily, was rather shy at first but later became quite aggressive. His behavior in the experimental situation was marked by intermittent periods of extreme activity which included whirling around and around very rapidly, racing in the apparatus, jumping, and rolling. He would break off in the midst of what gave promise of being an almost perfect trial and suddenly start racing or whirling. After some seconds of very vigorous activity, he would stop suddenly and sit very still for a time, then continue with the solution of the problem. This behavior would appear repeatedly over a period of days and then often would not reappear at all for days or even weeks.

Monkey C. Male. Weight, 88 ounces. Limit, 3 steps.

This monkey was in good physical condition, inclined to be fat. He tamed easily although he tended to be shy and "cautious" in his general behavior. In the experimental situation this shyness led to conditioning against the inner door.

Monkey D. Male. Weight, 106 ounces. Limit, 3 steps.

Subject D was a long, slender animal but in good physical condition throughout the experimental period. He was very wild upon arrival in the laboratory and one of the most difficult to tame. Even though given additional attention during the taming period and during the preliminary period in the apparatus, he was less tame than most of the other subjects.

Monkey E. Male. Weight, 104 ounces. Limit, 12 steps.

Subject E was long and slender in build. He was in good physical condition throughout most of the experiment. During the last two or three months he developed a chronic diarrhea which affected his general physical condition and may have hastened failure in the problem. However, he appeared to be well motivated to the end. Compared to the other members of the group, he was one of the wildest at the beginning and one of the least tractable throughout the entire experiment. He exhibited fear of the inner door almost from the beginning, at times refusing to enter the food compartment at all. During the training on Step II he developed a stereotyped habit of going in the wrong direction. The most drastic form of punishment (180 seconds' delay and no food at the end of the trial) was required to eliminate this habit. Nevertheless, during training on Step II and thereafter he was very persistent and almost tireless

in his efforts to obtain the reward even in cases of extreme difficulty and repeated failure.

Monkey F. Male. Weight, 99 ounces. Limit, 9 steps.

This subject was of medium build and in good physical condition. He was easily tamed, remarkably quiet and docile. Although fairly timid throughout the experimental period, he readily became adapted to the experimenter and to the experimental situation. During the training on Step II he developed a stereotyped habit of running directly to plate 2 and back to plate 1. This error became firmly established and severe punishment (180 seconds' delay and no food at the end of the trial) was necessary to correct it. However, in spite of this, his motivation remained at a high level.

Monkey G. Male. Weight, 75 ounces. Limit, 6 steps.

Subject G was slender in build but in good physical condition. He tamed readily and was very tractable throughout. At the beginning of the experimental period he formed the habit of reaching to the top of the cage in the region of the plate. Since he frequently touched the plate at the same time, this behavior often resulted in success, and it persisted for 136 trials. It was later resorted to in attacking new steps. Toward the end of the experimental period he exhibited considerable sex behavior in the apparatus.

Monkey H. Male. Weight, 75 ounces. Limit not obtained.

This subject appeared to be in good physical condition at the beginning and throughout most of the basic problem. However, he later developed a severe case of diarrhea and died shortly after completing the basic problem. He was wild at first but tamed without great difficulty. He was in general very active but his behavior in the apparatus was marked by little extraneous activity.

Monkey R. Female. Weight, 70 ounces. Limit, 2 steps.

This subject had not matured sexually before the end of the experiment. She was in excellent physical condition throughout. She was slightly aggressive but very tractable for the most part. Although she seemed to adjust readily to the experimental situation, her performance was characterized by considerable extraneous behavior. She developed the habit of racing in the apparatus, often going at such a high rate of speed that she was unable to stay on the floor but was forced to run on the walls of the box.

Monkey S. Female. Weight, 115 ounces. Limit, 3 steps.

This subject was estimated to be approximately 31 months of age

on the basis of sex maturity. She was in good physical condition although severe swelling of the entire posterior part of the body occurred. This appears to be a normal condition in the maturing female macaque. She was one of the wildest members of the colony upon arrival in the laboratory. However, she adjusted to the experimental situation quite readily.

Monkey T. Female. Weight, 114 ounces. Limit, 3 steps.

Subject T was estimated, on the basis of sex maturity, to be about 31 months of age. She was of stalky build and in good physical condition. Upon arrival she was the wildest of all of the females and the most difficult to tame. However, she was seldom aggressive toward the experimenter and, in spite of her size, was very timid toward the other monkeys. In the apparatus she was relatively inactive at first but later exhibited much extraneous behavior which seemed to be due largely to sex interest.

Monkey U. Female. Weight, 93 ounces. Limit, 4 steps.

Subject U was estimated to be about 30 months old on the basis of sex maturity. She was physically in good condition throughout. She was not difficult to tame. In the apparatus she was quite inactive at first, occupying much of the time during the first trials sitting by the entrance door, often screaming vehemently.

Monkey V. Female. Weight, 68 ounces. Limit, 13 steps.

This subject was judged to be about 25 months old on the basis of sex development. She was in excellent physical condition and was very active. She was not exceptionally wild but was inclined to be aggressive from the beginning. In the experimental situation she worked very fast when her activity was directed toward the plates. However, she displayed some extraneous behavior including whirling, jumping, rolling, and forming a swing by threading her cord through the wire at the top of the box and grasping the end with her hands and feet. She also had a peculiar trick, frequently resorted to, of hooking her left hind leg over her back and hobbling around on three legs. Whenever this form of locomotion was resorted to, the problem-solving performance was completely disrupted. It seems likely that this was a type of sex behavior. Frequently she would suddenly break off this extraneous activity and run through the problem very rapidly, making a perfect performance from that point on. Of all of the monkeys in the group, none of the others displayed such a wide range of distracting types of behavior.

Monkey W. Female. Weight, 86 ounces. Limit, 4 steps.

Subject W appeared on the basis of sex development to be about 25 months of age. She was in good physical condition and quite active. She was wild at the beginning and never became very tractable. In the apparatus she became conditioned against the door into the reaction compartment almost at the beginning. When the door was opened she would spring out of the entrance compartment and often with one leap grasp the wall of the inner cage. As the extreme fear wore off she would dart out quickly, always passing plate 1. This led to persistent errors which reappeared with the introduction of each new step.

Monkey X. Female. Weight, 70 ounces. Limit, 8 steps.

Subject X was probably about 30 months old as indicated by sex maturity. She was in good physical condition. She tamed very readily, was quiet, unaggressive, and on the whole the most tractable animal in the group. In the apparatus she was slow and "cautious" in her movements.

Monkey Y. Female. Weight, 72 ounces. Limit not obtained.

Monkey Y had not reached sexual maturity at the time of her death. Early in the experimental period she developed a tubercular cough and was quite inactive. After completion of the basic problem, she was isolated from the rest of the group and died shortly thereafter. She tamed quite readily and was never difficult to handle. In the apparatus she was inactive at first but later worked very well.

Monkey Z. Female. Weight, 73 ounces. Limit not obtained.

This subject had not matured sexually at the time she was dropped from the experiment. Upon completion of the basic problem, she was used for the preliminary work in standardization of shock. Due to the use of a relatively high shock, she became conditioned against the plates. For this reason she was not used in the advanced problem. This monkey was in excellent physical condition. She tamed readily and was slightly aggressive. She worked consistently in the experimental situation and displayed little distractibility.

The value of a learning experiment of this type which extends over a long period of time is to a great

extent dependent upon keeping the animals in normal healthy condition. The necessary confinement together with the absence of sunlight add greatly to this problem. The difficulties of keeping monkeys alive indoors over a long period of time and their susceptibility to tuberculosis are well known. With these facts in mind, a careful study was made in order to obtain the most favorable living-conditions possible. It was necessary to work out a well-balanced diet which would include all of the essential food elements as well as an abundance of those vitamins which would normally be supplied to a great extent by sunlight. After much correspondence and consultation with recognized authorities, and after trying out various combinations of foods, the following weekly diet was adopted and maintained throughout the experimental period:

	Morning	Afternoon	Evening
Sunday:	Milk and eggs	Wholewheat bread and carrot	Banana
Monday:	Milk and eggs	Boiled rice and celery	Banana
Tuesday:	Milk and eggs	Boiled potato and beet	Banana
Wednesday:	Milk and eggs	Wholewheat bread and lettuce	Banana
Thursday:	Milk and eggs	Boiled rice and celery	Banana
Friday:	Milk and eggs	Wholewheat bread and spinach	Banana
Saturday:	Milk and eggs	Boiled sweet potato and carrot	Banana

Milk and eggs were mixed in the proportion of two eggs to a quart of milk. Each monkey was given from one-fourth to three-fourths of a cup according to the requirements of the animal. In addition, two or three

peanuts were given each animal on Wednesday and Sunday. Also approximately 1/8 teaspoon of powdered Adex tablets was fed each monkey with the banana.

It will be noticed that while the morning and evening meals were kept constant from day to day variety was introduced into the afternoon meal. The latter consisted of some starchy food and a green vegetable. Although the food varied in kind from day to day, the amount of food was kept relatively constant in order to avoid variable effects upon motivation. The A and D vitamin content of the diet was considerably increased by the use of powdered Adex tablets. Various methods of giving cod-liver oil were tried without success. The monkeys showed extreme dislike for it and refused every kind of food with which it was mixed. The problem was finally solved by grinding Adex tablets to a fine powder and placing the powder in slits cut in the bananas.

As a further substitute for sunlight, the animals were given daily exposures to rays from a General Electric Sun Lamp (Model B, vertically adjustable, Mazda lamp, type S-1 bulb). It is noteworthy that the monkeys gave definite positive reactions to the rays of the lamp, usually selecting that spot where the rays were most intense.

Every animal was watched closely for any signs of indisposition. Although there was very little illness in the colony, a few mild cases of diarrhea did occur and two severe ones. The mild cases were quickly remedied by reducing the amount of green vegetables

fed to these subjects. Through careful observation the experimenter was able to determine the amount of greens required by each monkey. Occasionally two or three peanuts were added to the diet of those monkeys which showed a tendency toward diarrhea. The regulation of the diet was greatly simplified by the fact that the monkeys were caged separately. A veterinarian was consulted with regard to the more serious cases. The treatment prescribed was a dose of bismuth subnitrate about the size of an aspirin tablet every two hours during severe attacks until feces became dark.

That the system of diet and the general care of the animals were very satisfactory is indicated by the fact that with few exceptions the monkeys were kept in splendid physical condition throughout the entire experiment lasting over a period of nearly two years.

The daily schedule throughout the experiment was as follows:

Early morning—½ hour exercise.

Six to ten of the animals were released together in the runway for about thirty minutes. When more than ten animals were being housed in the laboratory, a part of them were given their exercise before the morning meal and a part after. During the exercise period they were exposed to rays from General Electric Sun Lamps.

7:30-8:00. Morning meal.

9:00-11:00. Cleaning cages and watering.

11:00-late afternoon. Experimental period.

The experimental period varied in length according to the number of animals being used and according to the difficulty of the problem.

Late afternoon. Afternoon meal.

The afternoon meal was fed at the end of the experimental period.

6:00 Evening meal.

Upon arrival in the laboratory a leather belt was placed on each monkey. Attached to each belt by a ring was a light chain approximately 8 inches long with a ring at the end. Onto this ring was snapped a longer chain which served as a leash. Each animal was caged alone.

In order to give the monkeys an opportunity to make a gradual adjustment to the general laboratory conditions, they were left undisturbed in their cages for the first few days, except for the necessary feeding and watering. At the end of a week the laboratory attendant began the daily taming process. Each monkey was taken out on the leash, fed sunflower seeds, and led around the laboratory. At the end of approximately two weeks the taming process was taken over by the experimenter and was continued until the animals seemed fairly well adjusted to the experimenter, i.e., would eat from the hand, etc. The minimum time allowed to elapse between the entrance of a subject into the laboratory and its introduction into the apparatus was five weeks. This varied with the tameness of the animals, additional attention being given the animals which were more difficult to tame. It also varied to some extent with the time of the experimenter, since it was impossible to start the last group of four monkeys for over two months after they were brought into the laboratory, due to the long hours required at that time by the other subjects.

It should be pointed out here that, during the period of adjustment in preparation for the regular experiment, the monkeys were not treated as rats usually

are, i.e., all given an equal amount of attention, including a certain number of days of preliminary handling and a certain number of days of adjustment to the apparatus. An attempt was made to bring them all up to the same degree of tameness and to get them all equally well adjusted to the apparatus. It was, therefore, necessary to give a great deal more time to some monkeys than to others. This was done by extending the preliminary period over more days and by giving the subjects more time per day. The desired end, of course, was only approximately attained, since the subjects varied greatly in temperament, some being more tractable after a few weeks of handling than others were after many months. Uniformity was observed to the extent that at no time were any of the monkeys treated as pets.

General Procedure

As soon as the monkeys were thought to be sufficiently tame, the process of adjustment to the apparatus was begun. For this purpose the experimental room was dark except for the small light over the entrance compartment. Each monkey was placed in the entrance compartment for five minutes daily for one week or until he appeared at ease. While in the compartment, raisins and bits of apple were dropped in to him.

When the subject appeared to be adapted, i.e., ate readily and moved about freely, the second stage of adjustment to the apparatus was introduced. For use in this connection, a tunnel 26½ inches long by 11¾

inches wide and 18⅞ inches high was constructed. It consisted of a heavy wood frame covered with wire mesh. This tunnel was placed in the apparatus to form a passage between the entrance compartment and the incentive compartment and made it possible for the monkeys to become accustomed to the apparatus without acquiring practice in reacting to the plates. In addition, it furnished a means of training them to return to the entrance compartment from the incentive compartment in response to the signal of opening the entrance door. This was a part of the training in preparation for the regular experiment in which it was necessary that the animals return to the entrance compartment at the end of each trial. During the preliminary period they were trained to run through the tunnel to obtain food in the incentive compartment and then to respond to the opening of the entrance door by returning to the entrance compartment. The monkey was placed in the entrance compartment, the long chain was removed, and a long cord having one end attached to the outer part of the compartment was slipped through the ring of the short chain. This cord was long enough to allow the monkey to enter and explore the food compartment without restraint. The large light was then turned on over the main box, the inner door left open, and the entrance door slowly raised. When the monkey had passed into the tunnel, the door was closed behind him, and when he had entered the incentive compartment the inner door was closed. When he had eaten the food, the doors were opened and he was allowed to return to the en-

trance compartment. However, if he did not return within one minute, encouragement was given by slight pulls on the long cord. Seldom was it necessary to pull the animal back forcibly. These trials were increased from one to five per day and were continued until the animal had learned to return to the entrance compartment without aid from the experimenter. The entire period of adjustment to the box required from two to four weeks, depending upon the animal.

Even though the monkeys learned to respond to the signal of the opening of the entrance door by returning to the entrance compartment during the preliminary period, it sometimes happened that with the beginning of the regular experiment, when the tunnel was removed, they failed to respond to the opening of the door. In case the monkey failed to return at once in the regular experiment, one of a variety of methods was used to obtain this end. Usually if the experimenter walked to the side of the apparatus the monkey would go directly into the entrance compartment. However, a few of the animals were inclined to run around in the apparatus. For these it was necessary to use more drastic measures, such as catching their cord with a long hook and pulling them directly from the incentive compartment into the entrance compartment. The most difficult case was that of subject A, a very active and playful monkey. After approximately two months of rigid training during which at the end of each trial the doors were opened simultaneously and he was quickly pulled through to the entrance compartment, this subject gave no more

trouble but returned voluntarily when the doors were opened.

Each animal was started on the regular experiment as soon as it had learned to return through the tunnel to the entrance compartment at the signal of the raising of the door. The exact procedure for each trial in the regular experiment was as follows:

1. The box was baited and lights turned off in the room, leaving only the small light over the entrance compartment and the experimenter's pilot light. Both the entrance and the inner doors were closed. (The tunnel had been removed from the box.)

2. The monkey was taken from the living-room, led into the experimental room and placed in the entrance compartment. (By this time the long chains were no longer necessary but had been replaced by cords of window-sash size which were tightly secured to the rings of the short chains. These were left on when the monkeys ran through the apparatus.)

3. The experimenter sat down at the control table and turned on the large light over the apparatus.

4. The door into the reaction compartment was raised.

5. As soon as the animal had entered the compartment, the door was lowered behind him.

6. When the animal touched off the necessary plate or plates, the inner door opened and he was given access to the food.

7. When he had eaten the food, the entrance door

was opened and he returned to the entrance compartment.

8. The box was then reset for the next trial.

The incentives used were one raisin and one piece of apple about the size of a small raisin. The monkeys were allowed to obtain both bits of food at the end of each successful trial. The selection of these incentives was determined by a series of food tests made during the taming period of the preliminary group. Tests of food preferences were made by presenting in pairs equal-sized pieces of different kinds of food and recording the choices of the animals. The types of food used in the tests were: apples, sunflower seeds, raisins, grapes, bananas, oranges, peanuts, and dates. The most frequently chosen food was apple, grapes ranking second. However, since raisins also were chosen very frequently, it seemed better to use them in combination with the apple because they provided greater contrast to apple than grapes would.

The purpose of using two kinds of food was to keep motivation more constant. The monkeys varied somewhat in their choices and it seemed likely that a given monkey would vary over a long period of time. The use of two widely different kinds of food which were relatively high in incentive value under the test conditions seemed the most satisfactory method of equalizing these differences. The foods selected, apple and raisin, proved to be very satisfactory since they remained high in incentive value throughout the entire experiment. With the beginning of the regular ex-

periment and thereafter both apples and raisins were strictly excluded from the diet except as incentives.

In addition to these regular incentives, approximately six sunflower seeds were fed from the experimenter's hand upon returning the monkey to the living-quarters after each set of five trials. This was done for the purpose of keeping the subjects tractable.

Punishment in the form of delays in obtaining the food was used in a number of cases where certain stereotyped errors developed which required special treatment. When the animal went through the trials three times in succession in the same stereotyped manner, which involved one or more errors, a delay of 15 seconds was introduced, i.e., instead of allowing the inner door to open, it was held shut for 15 seconds. The animal was then required to touch off the plates in a manner not involving the stereotyped habit before the door was opened. Obviously the delays varied in length depending upon the time taken by the animal to work the problem after the 15 seconds. In some cases these delays were ineffective and the punishment was increased to 180 seconds' delay with no food at the end of the trial, i.e., after 180 seconds the animal was recalled to the entrance compartment. Such severe punishment was used only as a last resort and when the animal was sufficiently motivated to make it practicable.

The distribution of practice was kept as uniform as possible. Step I was begun with one trial per day and gradually the number was increased to five depending upon the success of the animal. Beginning

with Step II and thereafter the subjects were given ten trials per day in sets of five. The entire group of monkeys was run through the first set in a given order and then, beginning over again, they were run through the second set in the same order.

The norm of mastery used was nine perfect trials out of ten. A perfect trial consisted of a direct response to the plate or plates in the required order without any extraneous behavior and an immediate entrance into the food compartment. Where a series of plates was involved, it was necessary for the animal to indicate the end of the series, either by hesitating on the last plate or starting directly toward the door. If such an indication was given before the last plate in the series was reached, it was counted as an error. A given subject was trained on each step until it reached this degree of mastery and then it was immediately transferred to the next step.

There were three types of trials, based on the performance of the subjects: perfect trials, failure trials, and corrected trials. Perfect trials were those in which the subject responded directly to the plate or plates in the required order without any extraneous activity and entered the food compartment without delay. Failure trials were those in which the animal did not succeed in touching off the necessary plate or plates in the time allotted. In such cases, when the time limit was up the subject was recalled to the entrance compartment and, of course, received no reward. Corrected trials, involving one or more errors, ranged all the way from almost perfect trials to near failure

trials. That is, the animal was allowed to obtain the food if it depressed the necessary plate or plates in the proper temporal order and approached them from the required direction, even though a number of errors might have been interjected from time to time between the correct reactions to the several plates. For example, an animal might complete a part of the pattern correctly, then make a number of errors, and later return and continue the pattern, completing it within the three minutes. Illustrations of the kind of behavior involved will be given in connection with descriptions of the various problems. These trials were called corrected trials because the animal, after starting the pattern and then making errors, was allowed to correct its errors by picking up the pattern again at whatever point it was broken off. Obviously they were "corrected" only from the point of view of the experimenter and not necessarily from the standpoint of the animal. These trials were successful in the sense that the monkey obtained the reward.

This procedure was necessary in order to maintain motivation at a high level. Otherwise the tasks would have been so difficult as to cause a piling-up of failure trials (no reward allowed) and consequent discouragement of the subjects. Furthermore, it is in accord with the usual practice in maze problems. In maze work, the rat is allowed to obtain the food when it finally reaches the food compartment even though it has entered many culs-de-sac on the way. The rat is not required to return to the starting-point and run the entire maze correctly before obtaining the reward;

in fact, in many cases he is prevented from retracing at all.

Detailed and careful behavior records were taken. The time for each trial from the entrance of the animal into the reaction compartment to the touching-off of the last plate in the series was taken. To facilitate the taking of other behavior records the floor of the box was theoretically divided into quadrants. Quadrant A extended from an imaginary line running from the center of the entrance door to the center of the inner door, to a line cutting through the center of plate 1; quadrant B from the center of plate 1 to the center of plate 2; quadrant C from the center of plate 2 to the center of plate 3; and quadrant D from the center of plate 3 to the center of the door or the boundary indicated for quadrant A. By reference to these quadrants it was a fairly easy matter to indicate the path taken by the animal as well as to indicate the direction from which the plates were approached.

The usual learning scores of number of trials, errors, and minutes were obtained from the records taken. These scores will be presented and discussed in a later section of this study.

In addition to the learning scores, a number of others, which for convenience may be classed as activity scores, were obtained. These include the total number of plates depressed, total number of quadrants traversed, number of plates touched per quadrant traversed, number of plates touched per minute, number of quadrants traversed per minute, together with a complete analysis of the various types of errors made.

By means of these scores it was possible to give a relatively complete description of behavior in quantitative terms.

A description of various other kinds of behavior activities was included in the record which was useful in interpreting various behavior scores.

Special Procedure for the Various Problems

The study can be conveniently divided into a basic problem and an advanced problem. Although, in general, the procedure for both problems was identical, there were a few points of difference which should be indicated.

Basic Problem. The basic problem consisted of three steps. A description of the problem will be best understood by reference to the floor plan shown in Figure 3. In Step I the monkeys were trained to depress plate 1, the first plate to the right as they entered the reaction compartment. In Step II plate 2 was added, i.e., the animals were trained to depress plates 1 and 2 in order. In Step III plate 3 was added to the series so that it was necessary to depress plates 1, 2, and 3 in order. As indicated above, each step was mastered to the degree of nine perfect trials out of ten before the subject was transferred to the next step.

As mentioned in the previous section, the animals were allowed to obtain the reward on what were called corrected trials if they depressed the necessary plate or plates in the proper sequence and approached them from the required direction regardless of the number

or kinds of errors which might have been interjected between the correct reactions. A few specific examples of this type of trial will make this part of the procedure clear. On Step I, since only one plate was involved, the only requirement was that the animals step on this plate when going in a counterclockwise direction. Many errors, such as pulling at the inner door, climbing, circling the cage, touching off the other plates, and even touching off plate 1 while going in a clockwise direction, might have been made before the plate was approached and depressed from the required direction. Nevertheless, the animal was allowed to obtain the reward as soon as he made the appropriate response, i.e., depressed the plate while running in a counterclockwise direction, within the time limit.

In Step II plates 1 and 2 were to be depressed in order. The subject was required to approach the plates while going in a counterclockwise direction and to depress first plate 1 and later plate 2. He might make many errors before reacting to plate 1, and many more errors, such as repeatedly working at plate 1, running to the inner door, depressing plate 3, and depressing plate 2 from the wrong direction, before making the correct reaction to plate 2. However, if he had previously depressed plate 1 from the required direction, he was allowed to obtain the reward as soon as he depressed plate 2 from a counterclockwise direction. The same principle held for Step III. For example, if the monkey made the correct reaction to plate 1, omitted plate 2, and depressed plate 3, he might still obtain the reward after many intervening

errors if he finally depressed plate 2 and later plate 3 while running in a counterclockwise direction. He might even depress only plate 1 on the first trip around the cage, plate 2 on a later trip, and plate 3 on a still later trip, and yet obtain the reward provided all three plates were depressed in the required temporal order and direction, regardless of the number or type of intervening errors. In other words, the subject was allowed to make corrections by picking up the pattern at any point where it may have been broken off. He was thus not required to begin again at plate 1 and to repeat the whole pattern perfectly before obtaining the reward on a given trial.

It was necessary to place a time limit on the trials, otherwise some of the subjects would have required a very long time before they succeeded in depressing the necessary plate or plates. If at the end of the allotted time the monkey had not succeeded in touching off the plates, it was recalled to the entrance compartment and the trial recorded as a failure. The trials were limited to either three or five minutes. At the beginning of the experiment a limit of five minutes was used. However, as the experiment got under way, it was observed that the monkeys seldom succeeded after three minutes and, since during the heavy part of the work the experimental period extended over such a long portion of the day that it was impossible to maintain a proper feeding schedule, it was necessary to reduce the time to three minutes.

The criterion for failure on each step was 2000 active trials, i.e., if after 2000 trials the animal had

not succeeded in reaching the norm it was considered to have failed the step. By an active trial is meant one in which the animal continued to react to the plates in an apparent effort to obtain the food.

All of the seventeen subjects were trained on the three steps of the basic problem.

Advanced Problem. The advanced problem was a continuation of pattern behavior beyond the basic problem and consisted in increasing the complexity of the series. This increase was secured by the addition of another plate at each new step until the animal had reached its limit in ability to learn. Furthermore, the advanced problem involved a reversal of direction of running at each even-numbered step. An example of this is shown in Figure 3. The dotted line indicates the correct path for Step IV, i.e., the first step of the advanced problem. This step involved depressing plates 1, 2, 3, and 2 in order. The animal was required to reverse its direction after touching off plates 1, 2, 3 and go back to plate 2 in reacting to it the second time. If he continued around past the door, *D*, and touched off plate 2 while going counterclockwise, the door was not opened. In Step V the series was 1, 2, 3, reverse to 2 and 1. In Step VI plate 2 was added, thus requiring another reversal, i.e., plates 1, 2, 3, reverse to 2, 1, and reverse to 2. In this way the series was increased by one plate at a time until it was extended to 23 plates.

The same principle of procedure was carried out here as on the basic problem in regard to allowing the subjects to obtain the reward in the corrected trials in

which errors were involved. The subjects were merely required to react to the plates from the proper direction, and in the proper temporal order, within the three minutes allowed, in order to obtain the reward. They were allowed to pick up the pattern at whatever point or points it was broken off and to make corrections from there on. They were not required to begin at plate 1 again and repeat the whole pattern on a given trial before obtaining the food. The activities intervening at the various points of interruptions in the pattern were recorded and the number and types of errors tabulated. However, these errors, even though they might be stepping on wrong plates or reacting to the right plates from the wrong direction, did not prevent the animal from obtaining the food at the end of the trial if he later took up the series and completed it within the three minutes allowed for the trial.

A fairly simple illustration of a subject making a corrected trial on Step IV will help to make this clear. It may aid the reader, in following the movements of the subject, to refer to the floor plan in Figure 3. On this step the subject was required to depress plates 1, 2, 3, reverse his direction and depress plate 2. The plates were to be depressed in the proper temporal order and from the indicated direction before food was obtained. However, after depressing plate 1 (correct), the subject might omit plate 2 (error), depress plate 3 and reverse to plate 2. At this point he has merely the response to plate 1 to his credit. Now he might continue from plate 2 to plate 1 (error), then reverse his direction and go back to plate 2 (correct).

He now has plates 1 and 2 to his credit. He might then continue around to the door (error) passing plate 3 and later, continuing in a counterclockwise direction, depress plate 3 (correct). At this point he has plates 1, 2, and 3 to his credit. He might now continue in a counterclockwise direction (error) around the cage to quadrant C between plates 2 and 3, then reverse his direction and depress plate 2 (correct). With this last response to plate 2, the inner door would open and he would be allowed to obtain the food. It is obvious that, within the range of these various activities, the subject has actually run through the series of plates in the proper order and direction. Similar illustrations might be continued indefinitely but this example indicates the general principles followed for the trials on all of the steps.

It is understood, of course, that in every case the subject was required to learn each step until he reached the norm of nine perfect trials out of ten before he was transferred to the next higher step. When a monkey failed to attain this norm of mastery, according to the *criteria set for the problem, he was considered to have* reached his limit and was carried no further in the experiment.

In Step IV, as in the three steps of the basic problem, the criterion of 2000 active trials for failures was used. However, some of the monkeys consistently made failure trials, i.e., consistently failed to touch off the plates in the required order during the three minutes allowed for the trials and did not obtain the food. For these cases a criterion of 100 consecutive failure trials

was used. This seemed sufficient since none learned any of the advanced steps after ten consecutive failure trials. Long before the one-hundreth trial the animal had become inactive and ceased to work at the solution of the problem. This criterion was used in all of the advanced steps but for those steps beyond the fourth the criterion for failure in the case of active trials was reduced to 1000 trials. This seemed fair since none learned any of these steps after 630 trials. As a matter of fact, all of the subjects were actually given more than 1000 trials and one as many as 1775 trials.

As the series increased in length, the monkeys ran more rapidly, and it became increasingly difficult for the experimenter to determine whether or not the subjects gave the necessary indication of the end of the series. For this reason the automatic device which released the inner door the moment the final plate of the series was depressed was not used in the advanced problem. As already indicated, the door could be released by means of a switch on the control table. This switch was used throughout the advanced problem, making it possible to delay the opening just long enough for the subject to indicate his reaction before he could receive any signal from the opening of the door. Thus, if he hesitated on the plate or started toward the inner door the response was correct, but if he continued or turned toward the next plate the response was wrong and counted as an error.

In the advanced problem shock was supplied in the plates to serve as a cue in learning the various steps. It was used only when the monkey touched the wrong

plate. The shock was produced by an alternating current of 60 cycles, with a terminal pressure of 500 volts, an external resistance of 10,000,000 ohms in the circuit, and a current of 0.05 milliamperes. The apparatus which controlled the current was the Jenkins Stimulation Apparatus which is described in detail by Jenkins, Warner, and Warden (32). The setting in terms of the apparatus was 500 volts with the resistance at step C (step 3 on the instrument).

In testing out various degrees of electrical stimulation, the voltage was kept at 500 while the resistance was varied. The various settings of the apparatus tried out were as follows:

Voltage	Resistance		Milliamperes
	Step	Ohms	
500	A	16,000,000	0.031
500	B	13,000,000	0.038
500	C	10,000,000	0.050
500	D	8,000,000	0.063
500	E	6,000,000	0.083

Steps A, B, C, D, and E correspond to the series 1, 2, 3, 4, and 5 as marked on the instrument board. They are here referred to by letter to avoid confusion with the numbered steps used in connection with the problems.

The shock to be used was determined by experimentation with three subjects of approximately the same age and weight as those used in the regular experiment. The work extended over a period of about two months. The final decision to use step C was largely determined by one subject which had previously learned the basic

problem and thus was comparable in training with the regular subjects used in the advanced problem. The tests were made with the subject during the period of training on Step IV. The instrument was first set at step A. After a few trials at this point, the shock was increased one step at a time until it reached step E. At this point, the subject became conditioned against the plates and refused to work. Shock was then omitted entirely until this negative behavior disappeared. When the subject began reacting to the plates regularly again, shock was introduced with the instrument set at step D. The subject now became conditioned against this lower shock. The shock was then reduced to the next step below, or that used in the regular experiment.

In order to obtain the best results with regard to the limits of learning, it was necessary to use a relatively light shock to serve merely as a signal. This was true because if severe punishment were used the subjects would be likely to become conditioned against the plates, as actually happened with one subject used in the test experiment.

A type of delay-punishment slightly different from that mentioned in the previous section on general procedure was found necessary in certain cases in the advanced problem. It sometimes happened that on the higher steps which ended with plate 2 there was a tendency for the animal to continue on to the next plate instead of stopping at plate 2. This occurred especially with subjects which ran very fast, as was true of A and V. In these cases, it was necessary to open the

door immediately after the final plate was touched but to close it again quickly when the subject touched the next plate. He was then required to touch off the final plate (plate 2) again before being given access to the food. By the use of this method the error was always quickly eliminated.

Thirteen subjects were used in the advanced problem. This included all of the monkeys used in the basic problem with the exceptions of H, R, Y, and Z. As was indicated in the section on protocols, H and Y died before beginning the advanced problem; Z was employed in the preliminary work on shock and so could not be used thereafter in the regular experiment; R was eliminated because she failed Step III after being given 2000 trials and therefore was not used in the advanced problem.

It is evident from the preceding description that the chief differences introduced into the advanced problem were the reversal pattern to be learned and the use of shock to give cues. The division into basic and advanced problems has been made merely to simplify the discussion of the procedure and the treatment of the results. These two parts are to be regarded as one experiment, the chief aim of which was to determine limits of learning. However, the steps did not progress by equal units of difficulty. This will be made evident with the presentation of the results. The greatest increase in difficulty occurred at Step IV where the reversal of direction was first introduced into the task.

III

THE BASIC PROBLEM

The data obtained in connection with this experiment, as already indicated, may be divided into two classes, learning data and activity data. Under learning data are included trial, error, and time scores. Under activity data are included all of the scores representing a more detailed analysis of behavior. The division has been made for convenience and is somewhat arbitrary since the two groups of data are closely interrelated.

Learning Scores

The individual learning scores for the seventeen monkeys in the three steps of the basic problem are presented in Table 1. These scores represent the learning period up to, but not including, the norm. Thus, the last eight or nine trials were dropped off, depending upon whether there were nine or less perfect trials in succession. As indicated in a footnote to the table, 580 trials for subject E and 715 trials for F were omitted. These trials represent a long period of time during which the subjects were permitted to repeat stereotyped errors without any effort being made to break up the habits. In the case of E, the error was circling the box in the wrong direction; of F, going directly to plate 2 and back to plate 1. In both records the trials have been omitted from the point where there had been three successive stereotyped repetitions of the error on a given day to the point where a definite

TABLE 1

RESULTS OF BASIC PROBLEM SHOWING INDIVIDUAL LEARNING SCORES

Animals	Trials Total	Trials Failure	Trials Perfect	Errors, total	Minutes, total
		STEP I			
Males					
A	191	1	25	537	52.30
B	88	2	4	381	46.58
C	218	60	24	1078	437.65
D	301	152	29	866	776.87
E	199	5	5	1053	160.83
F	58	23	2	323	169.50
G	197	52	2	430	210.88
H	19	2	2	62	25.05
Females					
R	84	4	5	439	59.90
S	176	40	18	546	307.88
T	191	163	2	515	644.55
U	295	264	3	675	970.87
V	237	171	19	573	533.93
W	310	140	24	730	452.90
X	142	71	26	221	265.93
Y	34	14	7	98	80.50
Z	22	1	4	60	17.90
		STEP II			
Males					
A	461	0	100	1095	99.42
B	285	0	38	721	111.42
C	51	3	16	120	32.78
D	417	15	143	1022	203.73
E*	609	2	81	1463	113.28
F†	308	8	31	982	149.87
G	49	13	14	394	46.15
H	61	0	5	101	30.67
Females					
R	80	0	19	220	19.02
S	52	22	5	219	93.60
T	12	5	1	21	19.02
U	22	6	7	40	23.03
V	13	6	1	198	23.57
W	377	2	61	1336	90.77
X	60	6	13	146	55.57
Y	15	12	1	70	64.40
Z	12	0	1	92	13.65

*580 trials omitted. See page 434.

†715 trials omitted. See page 434.

TABLE 1 (*continued*)

Animals	Trials Total	Trials Failure	Trials Perfect	Errors, total	Minutes, total
			STEP III		
Males					
A	81	0	39	100	12.80
B	1640	21	265	2893	504.07
C	1	0	1	0	.12
D	56	1	20	113	19.53
E	297	4	117	331	57.85
F	36	6	10	270	36.67
G	98	0	42	122	16.53
H	17	0	4	30	5.30
Females					
R	Failed				
S	552	1	144	792	137.38
T	7	0	2	14	4.80
U	1	0	1	0	.17
V	66	0	24	139	8.48
W	234	0	88	383	32.80
X	101	6	23	338	61.53
Y	11	1	2	29	13.55
Z	2	0	1	3	.58

effort on the part of the experimenter to break up the habit was begun.

The total number of failure trials as well as the total number of perfect trials for each subject are shown in the table. As indicated in the preceding section on procedure, a failure trial is one in which the animal fails to touch off the necessary plate or plates in the time allowed and thus does not secure the reward. A perfect trial is one in which the subject goes directly from the entrance compartment, touches off the plates in the required sequence, and enters the food compartment without hesitation or extraneous behavior.

The failure trials indicated in Table 1 may be divided into two types, three-minute and five-minute

trials. As noted in the preceding section, a shift was made after the experiment was begun from a five-minute to a three-minute time limit for trials. Table 2 shows the distribution of the two types of failure trials for the various subjects in the three steps of the basic problem.

TABLE 2

FAILURE TRIALS, SHOWING DISTRIBUTION OF THE TWO DIFFERENT LENGTHS OF TRIALS

Animals	Step I Length of trials		Step II Length of trials		Step III Length of trials	
	Five minutes	Three minutes	Five minutes	Three minutes	Five minutes	Three minutes
A	1	0	0	0	0	0
B	2	0	0	0	12	9
C	58	2	0	3	0	0
D	112	40	0	15	0	1
E	4	1	0	2	0	4
F	23	0	7	1	0	6
G	0	52	0	13	0	0
H	2	0	0	0	0	0
R	4	0	0	0	—	—
S	40	0	0	22	0	1
T	65	98	0	5	0	0
U	84	180	0	6	0	0
V	0	171	0	6	0	0
W	0	140	0	2	0	0
X	0	71	0	6	0	6
Y	14	0	12	0	1	0
Z	1	0	0	0	0	0
Total	410	755	19	81	13	27

The individual scores were combined separately for each of the two sexes and also for the group as a whole. The measures of central tendency and of variability obtained for these groupings are presented in Table 3. Due to the small number of subjects and the great variability, the median may be considered a better measure of central tendency than the average. The median is

TABLE 3

SHOWING MEASURES OF CENTRAL TENDENCY AND VARIABILITY FOR TRIALS, ERRORS, AND MINUTES IN THE THREE STEPS OF THE BASIC PROBLEM

	Median	Average	Range	Quartile deviation	Average deviation	Standard deviation	Coefficient of variation
			STEP I *Trials*				
Males	194.00	158.88	19-301	70.50	69.88	88.43	55.66
Females	176.00	165.67	22-310	89.50	83.44	99.22	59.89
Combined	191.00	162.47	19-310	74.38	77.94	94.36	58.08
			Errors				
Males	483.50	591.25	62-1078	271.50	292.25	344.75	58.31
Females	515.00	428.56	60-730	218.75	189.56	231.43	54.00
Combined	515.00	505.12	60-1078	201.50	237.88	301.46	59.68
			Minutes				
Males	165.17	234.96	25.05-776.87	82.15	163.77	239.28	101.84
Females	307.88	370.48	17.90-970.87	234.31	242.00	296.05	79.91
Combined	210.88	306.71	17.90-970.87	196.94	222.24	279.14	91.01
			STEP II *Trials*				
Males	296.50	280.13	49-609	183.00	168.63	198.22	70.76
Females	22.00	71.44	12-377	22.88	57.44	110.58	154.79
Combined	60.00	169.65	12-609	142.75	159.53	189.25	111.55
			Errors				
Males	851.50	737.25	101-1463	451.00	403.25	460.92	62.52
Females	146.00	260.22	21-1336	83.13	194.44	386.97	148.71
Combined	219.00	484.71	21-1463	411.25	379.12	485.74	100.21
			Minutes				
Males	105.42	98.42	30.67-203.73	40.25	44.91	56.74	57.65
Females	23.57	44.74	13.65- 93.60	21.59	25.51	30.22	67.55
Combined	55.57	70.00	13.65-203.73	37.40	42.27	52.12	74.46

TABLE 3 (*continued*)

	Median	Average	Range	Quartile deviation	Average deviation	Standard deviation	Coefficient of variation
			STEP III *Trials*				
Males	68.50	278.25	1-1640	40.50	250.75	521.93	187.58
Females	38.50	121.75	1- 552	49.50	116.50	178.75	146.82
Combined	61.00	200.00	1-1640	47.00	183.63	397.88	198.94
			Errors				
Males	117.50	482.38	0-2893	120.00	421.63	917.13	190.13
Females	84.00	212.25	0- 792	167.50	200.75	261.76	123.33
Combined	117.50	347.31	0-2893	158.50	311.19	687.80	198.04
			Minutes				
Males	18.03	81.61	.12-504.07	15.69	72.92	160.60	196.79
Females	11.02	32.41	.17-137.38	16.11	28.90	44.17	136.29
Combined	15.04	57.01	.12-504.07	15.94	51.29	120.32	211.05

much smaller than the average for the total group in all cases except for trials and errors in Step I. This is particularly striking in Step III where subject B required 1640 trials to learn the step, while the animal ranking next required only 552 trials, and the one next in rank, only 297 trials. As a result, the average is almost three times as large as the median for errors, more than three times as great for trials, and almost four times as great for minutes. The discrepancies between averages and medians are on the whole greater for the females than for the males.

The performance of the experimental group is characterized by a very wide range, whether measured in terms of number of trials, errors, or minutes, showing that some of the monkeys learned very quickly and with few errors, while others required a very large number of trials and made an enormous number of errors. The other measures of variability also indicate extreme variability of the group. Due to the small number of cases and the spread of the scores, the quartile deviation is perhaps the most significant of these measures. However, the other measures are presented in order to make the data comparable with similar studies made of other animals.

Certain factors which may have contributed to this variability fall readily into two groups, those which relate to the set-up or conditions of the experiment and those which relate to individual characteristics of the subjects themselves. Several points should be discussed in connection with the first classification. The fact that at the beginning of Step I it was largely a

matter of chance whether the monkeys stepped on the plate would in itself tend to increase variability on this step. The variability of the scores, especially in Step I, is further increased by the fact that during the experiment a shift was made from a five-minute to a three-minute limit for length of trials. It has already been mentioned that this shift was necessary to save time and it was justified by the fact that the monkeys usually solved the problem within three minutes or failed to do so in five minutes.

It is quite probable that only the time scores are greatly affected, however, since the failure trials were usually comparatively inactive ones. This being true, the number of errors would not be materially affected. Furthermore, the influence upon number of trials is perhaps very slight. It is problematical as to whether the greater length of trials would tend to increase or to decrease the number of trials. It may be that the longer trials tend to encourage the habit of inactivity and thus might actually increase the number of trials necessary to learn. Since the failure trials represent a very small proportion of the total number of trials for Step II and an almost negligible proportion of the trials for Step III, this factor cannot be regarded as making a significant contribution to variability in these steps.

It might be argued that the use of a high norm, nine perfect trials out of ten, would tend to increase variability. For this reason, the data were computed for the three steps on the basis of two lower norms, four perfect trials out of five (norm 2), and one perfect trial (norm 3). In comparing the norm used (norm

1) with the two computed norms, it should be remembered that in each case the animal was continued on the step until he had reached norm 1, nine perfect trials out of ten. Thus in Steps II and III the data do not show what would have happened if the lower norms had actually been used in the preceding steps and the animals pushed on as soon as they reached these norms.

The measures of central tendency and of variability obtained by computing the data on the basis of norms 2 and 3, together with those obtained by the use of norm 1, are presented in Table 4. On the whole, the measures of central tendency indicate that considerably more trials, errors, and time were required to reach each succeeding norm. However, in Step I the differences between norms 1 and 2 are much less than between norms 2 and 3. The amount of overlapping of the scores is shown in Table 5. While this table indicates considerable overlapping of scores for all of the norms in each of the three steps, it substantiates the evidence for a much greater difference between the two lower norms than between the two higher norms in Step I.

In comparing the variability of the lower computed norms with the higher norm actually used, there seems to be no uniformity throughout the three steps. In Step I there is a trend toward decreasing variability with each higher norm. In Step II, according to the coefficient of variation, the greatest variability is shown for norm 2 in trials and errors, while variability for time is practically the same for all of the norms. In Step III the coefficient of variation indicates a trend toward increasing variability with increasingly higher

TABLE 4

SHOWING MEASURES OF CENTRAL TENDENCY AND VARIABILITY FOR TRIALS, ERRORS, AND MINUTES FOR THE THREE NORMS IN THE THREE STEPS OF THE BASIC PROBLEM

Norms	Median	Average	Range	Quartile deviation	Average deviation	Standard deviation	Coefficient of variation
			STEP I *Trials*				
1	191.00	162.47	19-310	74.38	77.94	94.36	58.08
2	165.00	141.12	19-293	68.88	80.12	89.06	63.11
3	46.00	86.41	8-291	42.38	61.59	85.45	98.89
			Errors				
1	515.00	505.12	60-1078	201.50	237.88	301.46	59.68
2	438.00	465.88	59-1051	262.63	251.18	310.63	66.68
3	248.00	303.06	6-871	168.25	211.76	260.35	85.91
			Minutes				
1	210.88	306.71	17.90-970.87	196.94	222.24	279.14	91.01
2	169.50	295.21	17.50-970.77	198.35	221.57	281.88	95.48
3	79.33	218.75	6.72-968.62	126.52	184.77	268.05	122.54
			STEP II *Trials*				
1	60.00	169.65	12-609	142.75	139.53	189.25	111.55
2	18.00	68.18	12-520	18.13	54.06	122.08	179.06
3	15.00	32.12	9-173	6.88	20.29	40.34	125.59
			Errors				
1	219.00	484.71	21-1463	411.25	379.12	485.74	100.21
2	102.00	233.35	21-1363	77.13	167.53	318.97	137.28
3	81.00	141.47	21-578	64.63	87.00	140.45	99.28
			Minutes				
1	55.57	70.00	13.65-203.73	37.40	42.27	52.12	74.46
2	30.67	38.68	3.38-107.68	18.04	23.08	29.00	74.97
3	23.57	29.98	2.42- 89.80	14.39	17.83	22.91	76.42

TABLE 4 (*continued*)

Norms	Median	Average	Range	Quartile deviation	Average deviation	Standard deviation	Coefficient of variation
			STEP III *Trials*				
1	61.00	200.00	1-1640	47.00	183.62	397.88	198.94
2	15.00	19.94	1-123	9.25	14.00	27.50	137.91
3	5.00	7.12	1-22	4.13	5.41	6.74	94.66
			Errors				
1	117.50	347.31	0-2893	158.50	311.19	687.80	198.04
2	29.00	56.71	0-286	27.25	47.35	77.73	137.07
3	9.00	31.24	0-213	15.25	30.00	53.21	170.33
			Minutes				
1	15.04	57.01	.12-504.07	15.94	51.29	120.32	211.05
2	5.30	16.08	.12-116.68	7.87	14.06	27.15	168.84
3	.98	6.08	.05- 35.65	2.33	5.79	10.24	168.43

TABLE 5

COMPARISON OF SCORES FOR THE DIFFERENT NORMS FOR TRIALS, ERRORS, AND TIME ON THE THREE STEPS OF THE BASIC PROBLEM, SHOWING PERCENTAGE OF SCORES FOR A GIVEN NORM WHICH REACHED OR EXCEEDED THE MEDIAN OF A LOWER NORM

Norms compared	Trials	Errors	Time
	STEP I		
1 and 2	41.2%	41.2%	47.1%
1 and 3	17.6	23.5	29.4
2 and 3	17.6	29.4	35.3
	STEP II		
1 and 2	23.5	29.4	35.3
1 and 3	23.5	17.6	29.4
2 and 3	35.3	35.3	47.1
	STEP III		
1 and 2	29.4	29.4	29.4
1 and 3	17.6	17.6	17.6
2 and 3	29.4	29.4	29.4

norms. From this analysis it does not seem that the high norm used had any definite influence upon variability.

The factors discussed above are related to the set-up of the experiment. There are also a number of factors, related to the individual characteristics of the subjects, which are of interest in connection with group variability. The more important are: differences in age, in tameness, in playfulness, in the formation of certain stereotyped errors of the position-habit type, in the occurrence of specific reaction tendencies, in the amount of transfer effect from step to step, and in genuine individual differences in ability to learn.

It might be thought that age differences contributed to variability within the group. It is impossible to determine just how great these differences were since the monkeys were obtained from an importer and their

exact ages could not be known. Weight and sex development were used as criteria of age. While the latter criterion was of little use in the case of the males, it was useful in the case of the females. Schultz's (12, Chapter II) estimates seem to indicate that the average age of female rhesus monkeys at the time of first menstruation is probably about 37 months. Using this as a criterion, two of the females, S and T, were approximately 31 months old when brought into the laboratory, while, at the other extreme, V and W were probably about 25 months old. Using the criterion of weight as indicated by Schultz's averages, the ages ranged approximately from 18 months (subject V) to 36 months (subjects S and T). It will be noticed that, according to the latter criterion, the age range is much greater than that indicated by the sex criterion. However, since Schultz's averages represent very few cases, and since he states that there are marked individual differences in rate of growth of the macaques, weight can be taken only as a very rough indication of age.

Taking the various factors into consideration, it seems fair to assume that the total group, when first brought into the laboratory, ranged from 24 to 31 months of age, with an average of 27 months. This estimate is supported by the fact that the two largest monkeys (females) were judged to be approximately 31 months of age on the basis of sex maturity. Furthermore, of the six smallest monkeys, all except one were females, and, on the basis of sex maturity, no female appeared to be less than 25 months of age. Since the smallest male was exactly the same weight as the

smallest female, one month's difference was allowed for this male, thus bringing the lower limit to 24 months. An age difference of 7 months seems relatively small when the total life span of approximately 30 years for the rhesus monkey is taken into account. Yet one might expect a real age difference in ability to learn since these animals probably had not yet reached maturity so far as growth and intelligence are concerned. They were young growing animals, sexually immature, at the beginning of the experiment.

However, there is little evidence to show that age differences actually had a significant influence upon variability of performance on the basic problem. There was no significant correlation ($-.27 \pm .16$) found between age (using weight as a criterion) and number of trials required to learn the three steps of the basic problem. Furthermore, of the two oldest subjects, S and T, the former ranked thirteenth and the latter fourth with respect to number of trials required to learn this problem. The two youngest subjects, B and V, ranked sixteenth and seventh respectively with regard to number of trials on the basic problem. However, the lack of statistical evidence in such a small group does not preclude the possibility of a genuine age difference in ability to learn.

Differences in degree of tameness probably did tend to increase variability. It was noted in the preceding section that such fundamental differences were present and could not be eliminated even by giving added attention to certain subjects. These differences would tend to increase variability in a number of ways. In

Step I, where the first success was largely a matter of chance, differences in tameness would affect the probability of the monkey's forming an association between a chance success in stepping on the plate and obtaining the food. Differing degrees of tameness would also make for differences in distractibility. Perhaps most important of all, lack of tameness or a tendency to shyness led to conditioning against various parts of the apparatus. As was indicated in the protocols, such conditioning did occur in the cases of subjects C, E, and W.

A number of other individual characteristics indicated in the protocols affected variability. A high degree of frolicsomeness clearly tended to increase the scores of some subjects. This was especially true of subject A. Perhaps much of the activity of B and R could also be classed as playful behavior. Certain specific habits, such as those developed by E, F, and G, served to increase the length of the training period for these monkeys. Subjects H, Y, and Z are examples of monkeys which tamed readily, developed no negative conditioning or stereotyped errors, exhibited little extraneous behavior of any kind, and consequently obtained the three best scores on the basic problem taken as a whole.

It seems probable that certain specific reaction tendencies peculiar to the individual were of some significance in determining the scores. This would seem to be indicated by the fact that there was little consistency in the relative difficulty of the several steps for the various individual subjects. As will be shown later,

Step I was, on the whole, more difficult than either Steps II or III. Nevertheless, Step I was easier than either of the other two steps for subjects B and E. It is quite probable these differences in relative difficulty are in some measure due to certain reaction tendencies, peculiar to the individual, which affect the rate of learning on one step more than on another.

Differences in transfer effects may also have been of importance. This factor is connected with the inconsistency in the scores of a given subject from step to step, and will be discussed in greater detail in connection with the advanced problem.

It seems that to some extent the wide differences in rate of learning represent real differences in ability to learn. However, the lack of consistency in the scores of a given animal shows that ability to learn cannot be judged on the basis of one step alone.

The question arises as to the relative difficulty of the various steps. The number of *trials*, *errors*, and *minutes* required to learn each step may be taken as indicative of the difficulty of the step. While the scores are too few and too variable to give reliable results, there are a few points worth noting. Table 3 shows that, based on measures of central tendency for the total group, there is on the whole a trend toward a decrease in number of errors made and length of time required to learn the three successive steps. The opposite trend appears to a slight degree for average number of trials, while the median number of trials is practically the same for Steps II and III. The significance of these trends is better shown by a comparison of the scores in

TABLE 6

COMPARISON OF LEARNING SCORES FOR THE THREE STEPS OF THE BASIC PROBLEM, SHOWING PERCENTAGE OF SCORES FOR ONE STEP WHICH REACHED OR EXCEEDED THE MEDIAN OF A SUBSEQUENT STEP

Steps compared	Trials	Errors	Minutes
I and II	23.5%	17.6%	23.5%
I and III	23.5	17.6	0.0
II and III	58.8	29.4	5.9

the various steps in terms of percentage of overlapping. Such a comparison is presented in Table 6, which shows much overlapping of scores throughout in number of trials and number of errors and also much overlapping of time scores between Steps I and II. There is little evidence of any real difference in difficulty between Steps II and III as measured by number of trials or of errors. The median number of trials required for Step II was 60 while for Step III it was 61. As shown by Table 6, 58.8 per cent of the trial scores for Step II reached or exceeded the median score for Step III. It is true that the median number of errors for Step II is greater than for Step III and also that only 29.4 per cent of the error scores in Step II were as good as, or better than, the median score in Step III. However, the fact that the percentage of overlapping of error scores between Steps I and II is exactly the same as that between Steps I and III seems to indicate that the difference between the medians of Steps II and III may be due to the smallness of the sample and consequent large gaps between the individual scores. *The percentages do seem to indicate*

that Step I was more difficult than either Step II or III.

The only real evidence for a trend toward decreasing difficulty with each succeeding step as indicated by this table is in the case of time scores. It is evident that on the whole the monkeys took the longest time to learn Step I, less time for Step II, and the least time for Step III. This speeding-up of activity from step to step probably means that the animals were better adjusted to the situation, ran faster, and worked more consistently at the task.

Since there was practically an equal number of males and females used in the experiment, it seemed feasible to compare the scores of the two sexes. However, the small number of cases and their extreme variability minimize the value of such a comparison. Table 7

TABLE 7

Comparison of Learning Scores for Males and Females on the Three Steps of the Basic Problem, Showing Percentage of Males Which Reached or Exceeded the Median of the Females

Steps	*Trials*	*Errors*	*Minutes*
I	37.5%	50.0%	75.0%
II	0.0	25.0	0.0
III	37.5	25.0	25.0
I, II, and III combined	25.0	12.5	75.0

indicates that in Step I the females were superior to the males only in number of trials, while in Steps II and III they were superior to the males in trials, errors, and time. However, when the three steps are combined, the males showed superiority in time scores.

The males were also superior as regards number of steps learned since one of the females failed Step III while all of the males learned the three steps.

A modification of the Vincent method was used to represent trends in errors and time. To lessen the effect of extreme cases, individual raw scores for each tenth of the learning period, as represented by number of trials to learn, were converted into percentages of the total score for a given subject, i.e., if an animal made 10 errors during the first tenth of the learning period and 50 errors during the entire learning process, his score would be 20 per cent for the first tenth. The composite percentages were then obtained by combining the percentage scores for all of the animals. Table

TABLE 8

SHOWING AVERAGE PERCENTAGE SCORES IN ERRORS AND TIME FOR EACH TENTH OF THE LEARNING PERIOD IN THE THREE STEPS OF THE BASIC PROBLEM

Tenths	Step I		Step II		Step III	
	Errors	Time	Errors	Time	Errors	Time
1st	13.15%	17.31%	17.21%	16.91%	12.12%	14.46%
2nd	13.86	17.56	14.36	13.66	11.45	11.57
3rd	14.45	19.18	11.72	12.64	11.21	10.97
4th	9.74	10.87	10.09	10.72	11.00	10.53
5th	8.89	7.56	11.04	10.47	11.97	9.94
6th	10.11	7.82	8.56	9.05	9.48	9.69
7th	8.40	7.07	8.64	9.78	7.21	7.56
8th	8.55	5.58	7.24	7.22	9.52	8.20
9th	7.31	4.21	6.02	4.73	7.35	7.69
10th	5.54	2.84	5.12	4.82	8.69	9.39
Totals	100.00	100.00	100.00	100.00	100.00	100.00

8 shows that the first point on the error curve for Step I would be 13.15. This means then that on the average the animals made 13.15 per cent of their errors during

the first tenth of the learning period. The final point on the same curve would be 5.54, showing that on the average only 5.54 per cent of the errors were made during the last tenth. The trends for time were obtained in exactly the same manner. In addition to decreasing the effect of the extreme cases this method of treating the data has the advantage of putting all of the trends on the same numerical basis and thus making them comparable in that sense.

As shown by Table 8, the error and time trends for Step I take the same general form with a rise on the second and third tenths and then a fairly consistent drop to the end. However, the time trend is the more exaggerated of the two, starting at a higher point, taking a rise, then a fairly steep drop, and ending at a point considerably below the final point of the error trend. This difference is due in part and possibly entirely to the greater length of the failure trials for some monkeys at the beginning. In regard to the initial rise, an analysis of the individual curves revealed the fact that twelve out of the seventeen error curves show a rise at either the second or third or both points while 10 of the 17 time curves show a similar rise. Such a rise is to some extent explained in the case of errors by the fact that a number of subjects exhibited very little activity of any kind at first and later became more active. However, this explanation would not affect the time trend. This initial rise in the curve would seem to relate to the difficulty in forming the habit of reacting to plates. In certain cases the first trials were successful and required very little time. These

trials, however, were followed by a series of failure or very poor trials, indicating that the early successes had probably been more or less accidental.

The trends for Step II differ from those for Step I in that there is no initial rise and the time and error trends are almost equal as to amount of drop.

In Step III there appears to be a general flattening of all of the trends as well as a greater unevenness. Reference to individual scores in Table 1 shows that two animals learned the step in one trial each and a third learned in two trials. Thus the individual curves for two monkeys are perfectly flat, and that for a third appears as a continuous level for the first half and a continuous lower level for the second half. The initial point is somewhat higher for the time trend than that for the errors trend. This same characteristic appears in 9 out of the 16 individual cases. The time trend then makes a more rapid descent to the seventh point after which it takes an upward turn. This would seem to indicate acceleration of activity through the seventh tenth and a slowing-up from that point on.

Activity Scores

The activity data involve a variety of scores which to some extent afford a quantitative description of the behavior of the monkeys during the learning process: (1) those scores which were obtained directly from the original data; (2) those scores which were computed from the original time and activity scores; and (3) those scores which were obtained by analyzing the

errors into various classes. It will be convenient to discuss these three groups separately.

The first group includes the number of plates depressed and the number of quadrants traversed. The total score for number of plates depressed for a given monkey on each step was obtained directly from the records by counting the total number of reactions to plates for that individual. This score was largely a measure of the amount of activity directed toward the plates in contrast to general activity. The number of quadrants traversed was also obtained directly from the records. As indicated in the section on procedure, the reaction compartment was regarded as being divided into quadrants. A record was made of the path taken by the subject throughout each trial in terms of these quadrants. The number of quadrants, then, was obtained by counting the number of quadrants the monkey actually traversed, as shown by the records. This score was, therefore, a rough measure of the total distance traveled by the animal. These original activity scores are fairly closely related to the learning scores and are definitely affected by the length of the learning period. For example, if an animal took a very long time to learn he would presumably touch off more plates and traverse more quadrants than if he learned very quickly. This would be true in cases where the animals worked consistently at the problem. However, it is not so true on Step I since some of the animals were very inactive at the beginning.

The original activity scores for the individual animals on the three steps are shown in the second and

third columns of Table 9. The corresponding measures of central tendency and of variability are pre-

TABLE 9

RESULTS OF BASIC PROBLEM SHOWING INDIVIDUAL ACTIVITY SCORES

Animals	Plates depressed	Quadrants traversed	Quadrants per plate	Plates per minute	Quadrants per minute
Males			STEP I		
A	357	625	1.75	6.83	11.95
B	224	534	2.38	4.81	11.46
C	256	1238	4.84	.58	2.83
D	233	1697	7.28	.30	2.18
E	337	435	4.26	2.10	8.92
F	51	428	8.39	.30	2.53
G	148	797	5.39	.70	3.78
H	17	62	3.65	.68	2.48
Females					
R	283	458	1.62	4.72	7.65
S	171	592	3.46	.56	1.92
T	31	815	26.29	.05	1.26
U	31	709	22.87	.03	.73
V	124	737	5.94	.23	1.38
W	182	974	5.35	.40	2.15
X	75	376	5.01	.28	1.41
Y	19	60	3.16	.24	.75
Z	21	30	1.43	1.17	1.68
Males			STEP II		
A	1555	2744	1.76	15.64	27.60
B	1003	1543	1.54	9.00	13.85
C	176	228	1.30	5.37	6.96
D	1459	3440	2.36	7.16	16.89
E*	1805	3237	1.79	15.93	28.58
F†	1041	2065	1.98	6.95	13.78
G	223	520	2.33	4.83	11.27
H	164	190	1.16	5.35	6.19
Females					
R	279	438	1.57	14.67	23.03
S	184	301	1.64	1.97	3.22
T	23	39	1.70	1.21	2.05
U	56	79	1.41	2.43	3.43
V	112	221	1.97	4.75	9.38
W	1525	2461	1.61	16.80	27.11
X	180	270	1.50	3.24	4.86
Y	37	58	1.57	.57	.90
Z	75	87	1.16	5.49	6.37

*580 trials omitted. See page 434.
†715 trials omitted. See page 434.

TABLE 9 (*continued*)

Animals	Plates depressed	Quadrants traversed	Quadrants per plate	Plates per minute	Quadrants per minute
Males		STEP III			
A	366	547	1.49	28.59	42.73
B	7955	13732	1.73	15.78	27.24
C	3	3	1.00	25.00	25.00
D	246	422	1.72	12.60	21.61
E	1363	1853	1.36	23.56	32.03
F	316	491	1.55	8.62	13.39
G	440	658	1.50	26.62	39.81
H	75	91	1.21	14.15	17.17
Females					
R	Failed				
S	2620	3693	1.41	19.07	26.88
T	31	35	1.13	6.46	7.29
U	3	3	1.00	17.65	17.65
V	341	440	1.29	40.21	51.89
W	1082	1557	1.44	32.99	47.47
X	517	675	1.31	8.40	10.97
Y	49	65	1.33	3.62	4.80
Z	7	10	1.43	12.07	17.24

sented in Table 10. The scores are shown separately for the males and females and for the total group. The medians and averages indicate consistent increases from step to step in the number of plates depressed. This might be expected because of the increase in the number of plates involved in the solution of succeeding steps. A similar trend appears in the average but not in the median number of quadrants traversed. The fact that the median number of quadrants is largest for Step I while the median number of plates is smallest on this step indicates that there was a large amount of activity not directed toward the plates. This is probably indicative of the difficulty of the initial learning to react to plates.

The measures of variability indicate marked individual differences in the number of plates touched and

TABLE 10

SHOWING MEASURES OF CENTRAL TENDENCY AND VARIABILITY FOR NUMBER OF PLATES DEPRESSED AND NUMBER OF QUADRANTS TRAVERSED

	Median	Average	Range	Quartile deviation	Average deviation	Standard deviation	Coefficient of variation
			STEP I				
			Number of plates depressed				
Males	228.50	202.88	17-357	102.50	92.88	115.41	56.89
Females	75.00	104.11	19-283	67.88	73.11	87.32	83.87
Combined	148.00	150.59	17-357	99.88	98.47	112.85	74.94
			Number of quadrants traversed				
Males	711.00	852.00	62-1697	405.00	439.75	519.91	61.02
Females	592.00	527.89	30- 974	295.50	256.78	308.55	58.50
Combined	625.00	680.41	30-1697	210.80	344.82	451.42	66.35
			STEP II				
			Number of plates depressed				
Males	1022.00	928.25	164-1805	641.50	661.75	623.38	67.16
Females	112.00	274.56	23-1525	70.63	219.67	449.01	163.54
Combined	184.00	582.18	23-1805	473.63	474.53	629.34	108.10
			Number of quadrants traversed				
Males	1804.00	1745.88	190-3440	1258.00	1125.65	1248.01	71.48
Females	221.00	439.55	39-2461	115.00	356.53	725.89	165.23
Combined	301.00	1054.18	39-3440	910.88	898.59	1198.83	113.72
			STEP III				
			Number of plates depressed				
Males	341.00	1345.50	3-7955	182.50	1185.50	2528.60	187.93
Females	195.00	581.25	3-2620	255.00	558.75	845.53	145.47
Combined	328.50	963.38	3-7955	243.00	872.13	1923.64	199.68
			Number of quadrants traversed				
Males	519.00	2224.63	3-13732	283.50	1972.88	4381.34	196.95
Females	252.50	809.75	3- 3693	332.50	781.50	1197.48	147.88
Combined	465.50	1517.19	3-13732	320.00	1383.56	3288.70	216.76

the number of quadrants traversed. These differences agree fairly closely with corresponding differences in the learning scores (Table 3). The same factors which contributed to variations from individual to individual in learning scores would seem to be involved here. These factors have already been discussed in some detail in connection with the learning scores.

A modified Vincent method (see page 452) was used to represent trends in number of plates touched and number of quadrants traversed. As shown by Table 11, for the most part these trends are of the descending

TABLE 11

SHOWING AVERAGE PERCENTAGE SCORES FOR NUMBER OF PLATES DEPRESSED AND NUMBER OF QUADRANTS TRAVERSED FOR EACH TENTH OF THE LEARNING PERIOD ON THE THREE STEPS OF THE BASIC PROBLEM

Tenths	Step I		Step II		Step III	
	Plates	Quadrants	Plates	Quadrants	Plates	Quadrants
1st	5.64%	10.19%	15.03%	13.58%	10.41%	10.56%
2nd	4.79	10.03	11.84	12.56	10.48	10.78
3rd	6.84	12.48	10.26	11.46	10.26	10.69
4th	8.97	10.70	9.46	10.05	10.13	10.64
5th	9.78	9.71	9.79	10.34	10.69	10.45
6th	11.10	11.51	8.89	9.26	10.15	9.77
7th	11.19	9.94	9.00	9.77	9.08	8.95
8th	12.37	9.49	8.37	8.07	9.84	9.91
9th	13.42	8.70	8.92	7.87	9.19	8.97
10th	15.90	7.25	8.44	7.04	9.77	9.28
Total	100.00	100.00	100.00	100.00	100.00	100.00

type. The one striking exception is the trend for number of plates depressed on Step I, which is of the ascending type. This shows a steady rise in the tendency to react to plates on this step. The fact that the corresponding curves on succeeding steps are of the

descending type indicates that the monkeys had acquired the habit of reacting to plates by the completion of Step I and that on succeeding steps the task became more definitely the selection of the correct plates in the correct order.

The second group of scores (computed scores) includes the number of quadrants traversed per number of plates depressed, the number of plates depressed per minute, and the number of quadrants traversed per minute. The quadrant-plate ratio was obtained for each individual on a given step by dividing the total number of quadrants traversed by the total number of plates depressed by that animal. It should be pointed out that a perfect score in number of quadrants per plate would be 1.00, i.e., in making a perfect trial on Step I the subject would touch off one plate and traverse one quadrant; on Step II he would depress two plates and traverse two quadrants, etc. Thus the quadrant-plate relationship for a perfect trial on any step would be a one-to-one ratio. This ratio gives a fairly accurate measure of the proportion of activity which was directed toward the plates. Obviously the proportion might be the same for a subject which required few trials to learn as for one which required a great many trials. For example, a monkey which learned a given step in 25 trials might by playfully running around in the box or skipping plates on some of the trials make a very high (poor) quadrant-plate score. Another monkey which required 250 trials might be, on the average, equally playful and skip about the same proportion of plates thus making his

quadrant-plate score practically the same as that of the monkey which learned in 25 trials.

The number of plates depressed per minute was obtained by dividing the total number of plates depressed by a given subject during training on a step by the total number of minutes required to learn the step. These scores represent, to a large degree, speed of activity and will be referred to frequently in this way. They, like the quadrant-plate ratio, are relatively independent of the rate of learning and might conceivably be identical for two monkeys one of which required many trials to learn and the other very few. For example, a monkey which learned a step in 20 trials might run at the same rate of speed as one which required 200 trials to learn it. It would seem that these computed scores give some indication of the adjustment of the animal to the problem situation. An animal which was well adjusted to the problem would tend to work consistently at the plates and thus obtain a relatively good quadrant-per-plate score. Likewise, as the animals became well adjusted they also became more active, thus tending to increase their speed-of-activity scores.

The scores for this second group (computed scores) for the individual monkeys are presented in the fourth, fifth, and sixth columns of Table 9. The corresponding measures of central tendency and of variability appear in Table 12. The measures of central tendency indicate a marked improvement in the quadrant-plate ratio from step to step, while the measures of variability show striking decreases in differences within the group. The wide range on Step I was probably due,

TABLE 12

Showing Measures of Central Tendency and Variability for Number of Quadrants per Plate, Number of Plates Depressed per Minute, and Number of Quadrants Traversed per Minute

	Median	Average	Range	Quartile deviation	Average deviation	Standard deviation	Coefficient of variation
			STEP I				
			Number of quadrants per plate				
Males	4.55	4.74	1.75- 8.39	1.51	1.73	2.13	44.94
Females	5.01	8.35	1.43-26.29	1.89	5.64	8.84	105.87
Combined	4.84	6.65	1.43-26.29	1.61	3.81	6.83	102.71
			Number of plates per minute				
Males	.69	2.04	.30-6.83	.90	1.57	2.30	112.75
Females	.28	.85	.03-4.72	.21	.70	1.40	164.71
Combined	.56	1.41	.03-6.83	.40	1.16	1.97	139.72
			Number of quadrants per minute				
Males	3.31	5.77	2.18-11.95	3.22	3.26	3.99	69.15
Females	1.41	2.10	.73- 7.65	.49	1.03	2.01	95.71
Combined	2.18	3.83	.73-11.95	1.08	2.37	3.60	93.99
			STEP II				
			Number of quadrants per plate				
Males	1.78	1.78	1.16-2.36	.34	.34	.41	23.03
Females	1.57	1.57	1.16-1.97	.10	.14	.21	13.38
Combined	1.61	1.67	1.16-2.36	.18	.25	.34	20.36
			Number of plates per minute				
Males	7.06	8.78	4.83-15.93	1.83	3.15	4.23	48.18
Females	3.24	5.68	.57-16.80	1.95	3.95	5.60	98.59
Combined	5.37	7.14	.57-16.60	2.96	3.96	5.23	73.25
			Number of quadrants per minute				
Males	13.82	15.64	6.19-28.58	4.97	6.09	7.93	50.70
Females	4.86	8.93	.90-27.11	3.14	6.25	8.99	100.67
Combined	9.38	12.09	.90-28.58	6.17	7.54	9.14	75.60

TABLE 12 (*continued*)

	Median	Average	Range	Quartile deviation	Average deviation	Standard deviation	Coefficient of variation
			STEP III				
			Number of quadrants per plate				
Males	1.50	1.45	1.00-1.73	.17	.18	.23	15.86
Females	1.32	1.29	1.00-1.44	.14	.11	.14	10.85
Combined	1.39	1.37	1.00-1.73	.14	.17	.21	15.33
			Number of plates per minute				
Males	19.67	19.37	6.62-28.59	6.20	6.58	6.97	35.98
Females	14.86	17.56	3.62-40.21	6.31	9.67	12.17	69.31
Combined	16.72	18.46	3.62-40.21	8.19	8.25	9.96	53.95
			Number of quadrants per minute				
Males	26.12	27.37	13.39-42.73	7.43	8:08	9.69	35.40
Females	17.45	23.02	4.80-51.89	9.80	12.95	16.71	72.59
Combined	23.31	25.20	4.80-51.89	9.32	11.43	13.93	55.28

in small part, to the chance factor, which affects this step more than later steps, and in larger part to the difficulty in learning to react to plates. With the learning of Step I this type of reaction was fairly well established for all subjects and consequently the differences from individual to individual with respect to the quadrant-plate scores were less on succeeding steps.

The measures of central tendency for speed-of-activity scores indicate large increases in the scores from step to step while the coefficients of variation show a trend toward decreasing variability. Thus the group as a whole shows a speeding-up of plate and quadrant activity and at the same time the variability within the group shows a decrease with each succeeding step.

A comparison of the computed activity scores for the several steps is shown in Table 13. On the whole, the table shows relatively little overlapping of the scores from step to step. This would seem to indicate that the superiority of the median scores on each succeeding step is of some significance. The greatest amount of overlapping appears between Steps II and III for

TABLE 13

COMPARISON OF COMPUTED ACTIVITY SCORES ON THE THREE STEPS OF THE BASIC PROBLEM, SHOWING PERCENTAGE OF SCORES ON ONE STEP WHICH REACHED OR EXCEEDED THE MEDIAN OF A SUBSEQUENT STEP

Steps compared	Quadrants per plate	Plates per minute	Quadrants per minute
I and II	5.9%	5.9%	11.8%
I and III	0.0	0.0	0.0
II and III	17.6	0.0	17.6

quadrants per plate and quadrants per minute. There is less overlapping between Steps I and II. The improvement in the quadrant-plate ratio together with the speeding-up of activity indicates better adjustment to the problem situation and a more consistent working at the task from step to step.

Some rather interesting differences were found between the males and females of the experimental group with regard to the activity scores. The percentages shown in Table 14 indicate that, while there is a considerable overlapping of scores, as a group the males were consistently superior to the females with regard to the rate of touching plates and traversing quadrants. This bears out the observation that, on the whole, the males were more active than the females. On the other hand, with the exception of Step I, the females were definitely superior with regard to the quadrant-plate ratio. In this connection it will be remembered that the females also were found to be superior to the males in trial and error scores on the basic problem (Table 7). Thus it appears that, in general, the females

TABLE 14

COMPARISON OF COMPUTED ACTIVITY SCORES FOR MALES AND FEMALES ON THE THREE STEPS OF THE BASIC PROBLEM, SHOWING PERCENTAGE OF FEMALES WHICH REACHED OR EXCEEDED THE MEDIAN OF THE MALES

Steps	Quadrants per plate	Plates per minute	Quadrants per minute
I	44.4%	22.2%	11.1%
II	88.9	22.2	22.2
III	100.0	25.0	37.5
I, II, and III combined	62.5	25.0	25.0

worked more slowly but more efficiently than the males on the basic problem.

The data for the speed-of-activity curves on the three steps are presented in Table 15. These trends were

TABLE 15

SHOWING AVERAGE NUMBER OF PLATES PER MINUTE AND QUADRANTS PER MINUTE FOR EACH TENTH OF THE LEARNING PERIOD ON THE THREE STEPS OF THE BASIC PROBLEM

Tenths	Step I		Step II		Step III	
	Plates per minute	Quadrants per minute	Plates per minute	Quadrants per minute	Plates per minute	Quadrants per minute
1st	.54	2.87	6.22	9.94	17.41	22.44
2nd	1.94	4.43	7.50	11.91	18.92	24.93
3rd	.97	3.05	8.68	14.25	19.37	26.81
4th	2.00	4.74	8.54	13.63	20.79	28.95
5th	3.53	6.89	10.52	16.59	21.31	28.39
6th	3.44	7.43	10.12	16.88	24.08	31.60
7th	3.99	8.33	9.45	15.41	27.48	35.03
8th	4.37	7.91	9.90	15.13	24.76	32.59
9th	7.78	12.03	13.93	20.51	26.59	33.67
10th	8.78	14.31	15.79	21.60	23.97	30.31

obtained by the regular Vincent method. The modified form was not used since the totals of these measures have no significance and the conversion of the raw scores into percentages of a meaningless quantity could scarcely be justified. Inspection of the table reveals the fact that the data readily fall into two continuous and almost parallel curves for the three steps. The curves for plates per minute and quadrants per minute thus shown would appear as ascending curves with a drop at the beginning of Step II to a point slightly below the ninth segment of Step I, but a continuous ascent at the beginning of Step III. The peak for

both curves is reached on the seventh tenth of Step III. Reference to individual scores in Table 9 shows that the increase in activity from step to step is highly representative of the group since in every case, with one exception, the score rises on each succeeding step.

The third general group of activity scores consisted of analysis scores, those scores which were obtained by analyzing the errors into various types or classes. A classification of the various types of errors was made in the light of observed behavior and a careful study of the records obtained. The classification used was as follows:

Omissions of plates 1, 2, and 3; wrong plates 1, 2, 3. The general rule throughout was to classify an error as an omission only when a single plate was omitted, the preceding plate and succeeding plate in the series having been touched. For example, in Step III if plate 1 was passed and plate 2 touched, the error was recorded as an omission of plate 1. However, if plates 1 and 2 were both passed and plate 3 touched, the error was recorded as wrong plate 3. Obviously in Step I there would be no omissions of plates 2 or 3 since these plates were not used in a correct solution of the problem. Likewise, there would be no errors of wrong plate 1. In Step II there would be no omissions of plate 3.

Wrong direction. Both starting the trial in the wrong direction and approaching the right plate from the wrong direction were included under this classification.

Irregular course. This classification included zigzagging back and forth in the apparatus which did not fall under any of the previous classes. This type of error was counted only once in a given trial.

Climbing. Climbing was counted only once for a single trial. The amount of time spent in climbing was the significant factor rather than the number of times climbing was resorted to. Unfortunately it was not possible to keep a time record on this.

Entrance door. This included going to or working at the entrance door.

Inner door. This included going to or working at the door to the incentive compartment.

Around. This refers to going around the incentive compartment without touching plates.

Running beyond. Running beyond means continuing to run around the box or to work at plates instead of stopping or running directly to the door when the last plate was touched.

Miscellaneous. This classification included mostly reactions which were extremely slow, and various incidental habits which were developed by certain subjects, such as reaching to the top of the cage instead of stepping on the plate, straddling the plate with all fours and then pivoting around it, jumping backwards in the direction of the plate and missing it, and touching the plate too lightly to depress it.

The errors were tabulated under these various classes for each monkey on each of the three steps. The number of errors for each class was then converted into a

percentage of the total number of errors made by the animal on the step. Thus, if on Step I a given monkey made 200 errors altogether and 10 of these errors were classified under *wrong plate 2,* then his score for *wrong plate 2* would be 5 per cent. This would indicate that 5 per cent of the errors made by this subject were of the wrong-plate-2 type. When all of the individual scores had been computed they were combined and averaged to obtain the figures for Table 16. The

TABLE 16

TYPES OF ERRORS, SHOWING THE DISTRIBUTION OF EACH ON THE THREE BASIC STEPS

Types of errors	Step I	Step II	Step III
Omission of plates:			
Plate 1	.91%	11.00%	19.80%
Plate 2	.00	2.99	8.74
Plate 3	.00	.00	3.63
Wrong plates:			
Plate 1	.00	18.11	14.07
Plate 2	3.12	4.26	9.49
Plate 3	6.83	11.98	11.16
Wrong direction	12.95	8.79	8.55
Irregular course	12.62	7.15	3.82
Climbing	10.21	5.88	3.45
Entrance door	12.44	8.12	2.90
Inner door	15.59	8.11	7.36
Going around:			
Counterclockwise	2.59	1.95	2.55
Clockwise	3.36	.36	.26
Running beyond	.91	1.30	.05
Miscellaneous	18.37	10.00	4.17
Total	100.00	100.00	100.00

score .91 for Step I in the first array indicates, therefore, that on the average only .91 per cent of the errors made by the monkey were of the type classified as omissions of plate 1.

The table shows that in each succeeding step there is a tendency for the percentage of errors having to do with the plates to increase and the percentage of extraneous errors to decrease. This might be expected since with each step one or more classes of errors concerned with plates are added. However, this trend appears in the individual classes of omissions of plate 1, wrong plate 2, and omissions of plate 2. There is a decided increase in the proportion of wrong-plate-3 errors from Step I to Step II followed by a very slight decrease for Step III. Errors of wrong direction would necessarily be classified between the two groups since, as indicated by the description above, a part of these errors were wrong reactions to plates and a part were not. Here as in the extraneous errors there is a descending trend from step to step.

It will be noticed that the three types of errors having the highest percentage frequencies for Step I are: miscellaneous, inner door, and wrong direction. For Step II they are: wrong plate 1, wrong plate 3, and omission of plate 1; and for Step III the same three classes but in the order: omission of plate 1, wrong plate 1, and wrong plate 3.

Table 17 presents the distribution of the various types of errors throughout the learning periods of Steps I, II, and III. To obtain these data, the individual records were first made up by finding separate totals for the various classes of errors for each tenth of the learning period. These sums were converted into percentages of the individual's total errors for the respective tenths. These percentages were then com-

TABLE 17

TYPES OF ERRORS, SHOWING THE DISTRIBUTION OF EACH THROUGHOUT THE LEARNING PERIOD ON THE THREE STEPS OF THE BASIC PROBLEM

Types of errors	Tenths 1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
					STEP I					
Omission of plates:										
Plate 1	.24%	1.60%	1.26%	.71%	.72%	.97%	.65%	.94%	2.10%	1.91%
Wrong plates:										
Plate 2	3.37	1.59	1.90	2.41	3.50	5.39	2.07	3.45	3.63	1.96
Plate 3	4.09	5.65	6.63	7.82	10.31	7.25	15.97	6.83	7.23	5.58
Wrong direction	9.18	7.86	9.37	10.91	17.64	13.82	21.37	15.10	16.51	14.16
Irregular course	10.60	11.69	12.17	13.43	11.32	14.52	11.72	14.93	15.58	14.99
Climbing	10.67	12.77	14.06	11.82	7.73	7.98	3.83	8.60	7.86	6.21
Entrance door	18.37	21.21	16.19	7.28	4.28	6.10	3.70	5.32	2.08	2.35
Inner door	16.45	16.88	14.24	12.88	14.93	12.78	7.10	8.17	6.65	23.12
Going around:										
Counterclockwise	2.78	2.85	2.37	3.74	3.26	1.92	3.36	1.62	1.24	.88
Clockwise	5.40	2.63	4.93	4.45	2.23	2.04	2.87	2.35	2.11	.69
Running beyond	.71	1.43	1.50	1.18	.00	1.96	.00	1.96	6.33	5.98
Miscellaneous	18.14	13.84	15.58	23.37	24.08	25.27	27.36	30.73	30.68	22.17
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
					STEP II					
Omission of plates:										
Plate 1	2.37%	6.21%	10.72%	8.81%	10.50%	16.93%	16.46%	14.10%	19.10%	29.49%
Plate 2	3.24	3.27	2.79	3.30	3.76	5.90	7.48	3.75	2.06	1.94
Wrong plates:										
Plate 1	31.98	19.11	13.63	7.91	15.41	10.54	11.87	9.17	9.36	2.18
Plate 2	3.03	6.33	5.42	2.23	3.50	2.42	4.71	4.35	4.79	6.11
Plate 3	10.17	12.78	12.80	13.55	10.08	10.04	17.29	12.68	13.18	17.49
Wrong direction	5.23	8.91	11.52	11.96	8.42	9.03	8.31	6.38	9.87	13.93
Irregular course	5.90	8.41	5.31	11.01	8.43	6.01	4.65	4.01	5.92	4.22
Climbing	5.91	9.37	4.68	9.89	2.80	2.61	4.80	5.20	9.15	2.72

TABLE 17 (*continued*)

Types of errors	Tenths 1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Entrance door	7.36	11.20	7.76	9.08	4.13	7.93	4.09	4.28	4.15	1.80
Inner door	9.64	4.16	4.47	8.54	13.84	3.37	5.26	5.41	4.13	4.35
Going around:										
Counterclockwise	.64	.84	1.42	1.94	1.21	3.10	4.02	3.29	1.96	3.08
Clockwise	.11	.31	.52	.37	1.04	.39	.00	.16	.00	.00
Running beyond	1.24	1.19	.28	1.45	1.60	1.81	.40	2.35	6.09	1.79
Miscellaneous	13.18	7.91	18.68	9.96	15.28	19.92	10.66	24.87	10.24	10.90
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
STEP III										
Omission of plates:										
Plate 1	11.25%	16.25%	25.89%	25.97%	24.11%	29.09%	29.00%	25.17%	27.47%	26.54+%
Plate 2	5.93	7.35	3.81	4.43	10.20	10.26	13.33	13.69	6.54	10.83
Plate 3	2.10	4.01	6.63	4.27	3.55	2.14	.40	2.35	6.52	1.69
Wrong plates:										
Plate 1	26.01	24.58	9.32	11.53	11.45	7.99	9.42	11.80	12.87	12.79
Plate 2	8.15	7.11	11.16	6.12	13.53	5.25	5.47	4.68	8.92	16.68
Plate 3	4.29	4.70	6.79	10.15	11.67	12.90	11.53	16.85	14.46	18.92
Wrong direction	4.30	3.61	6.14	6.81	10.38	10.05	9.40	8.38	7.96	7.24
Irregular course	5.64	3.45	3.45	2.98	2.84	.93	.93	.73	1.82	.96
Climbing	3.79	2.73	1.22	4.86	2.07	9.49	.45	5.95	1.23	1.44
Entrance door	5.78	2.86	1.96	1.41	.54	3.00	2.34	.40	1.92	.51
Inner door	5.95	6.72	4.34	4.29	4.94	3.59	8.19	4.35	6.93	5.17
Going around:										
Counterclockwise	.96	1.48	3.62	2.28	2.67	4.26	5.29	2.63	2.68	1.15
Clockwise	1.95	.00	.00	.00	.00	.00	.93	.00	.00	.00
Running beyond	.07	.00	.00	.00	.00	.00	.00	.00	.00	.93
Miscellaneous	13.83	15.15	15.67	15.10	2.25	1.05	3.32	3.02	.68	1.10
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

bined and averaged for the group. Thus, the first number in the table, .24, means that, during the first tenth of the learning period, on the average .24 per cent of the errors made by the monkeys were omissions of plate 1.

The table indicates that, in general, on Step I errors concerned with reactions to plates tend to increase in relative frequency, as do errors of irregular course, running beyond, and miscellaneous errors. On the other hand, errors of climbing, working at the doors, and going around the food compartment without touching the plates tended to decrease in relative frequency as learning progressed.

The data for Step II indicate upward trends for omissions of plate 1, wrong plate 2, wrong plate 3, wrong direction, going around counterclockwise, running beyond, and miscellaneous errors, while downward trends are shown for wrong plate 1, irregular course, and running to the entrance door. The most striking trends are exhibited in regard to decreasing reactions to plate 1. This is shown by the consistent decrease in the relative percentage of wrong reactions to plate 1 and by the consistent increase in the relative percentage of omissions of plate 1. As was indicated by Table 16, wrong plate 1 and omissions of plate 1 were both important types of errors in Step II, ranking first and third respectively in percentage frequency. In terms of behavior, then, the records indicate that, at the beginning of the learning period there was a strong tendency to work repeatedly at plate 1, in other words, to repeat the habit which was successful on the first

step. The tendency gradually diminished while there was built up the tendency to omit plate 1 entirely and run directly to plate 2. There is also a rising trend in wrong reactions to plate 3. Thus in the learning of Step II there appears to be an increasing emphasis on plates 2 and 3 at the expense of reactions to plate 1.

As might be expected, in Step III the most pronounced ascending trend occurs for wrong reactions to plate 3. Omissions of plates 1 and 2 also show ascending trends although quite irregular. The trend for wrong reactions to plate 1 is almost the converse of that for omissions of plate 1 showing a steep drop to the third point, then a slight rise, another drop at the sixth point, and then a gradual rise to the end. So far as reactions to plates are concerned, then, there is an increasing tendency to react to plate 3 and possibly to plate 2, and a decreasing tendency to react to plate 1. Again, as in Step II, there is an increasing tendency to run directly to plate 2, omitting plate 1, a decreasing tendency to return to plate 1 after it has once been depressed, and an increasing tendency to react to plate 3 directly or before the other plates have been depressed in order.

Since the predominance of certain types of errors and the absence of certain others might be closely related to the rate of learning, a comparison was made of the types of errors for two extreme groups. Table 18 presents average percentages for the different types of errors made by the four best subjects in comparison with averages of the four poorest subjects for each of the three basic steps. The subjects were selected on

TABLE 18

COMPARISON OF EXTREME GROUPS, SHOWING DISTRIBUTION OF THE VARIOUS TYPES OF ERRORS ON THE THREE BASIC STEPS

Types of errors	Step I Superior	Step I Inferior	Step II Superior	Step II Inferior	Step III Superior	Step III Inferior
Omission of plates:						
Plate 1	.47%	.65%	.00%	23.59%	6.01%	35.58%
Plate 2	.00	.00	3.96	2.66	9.37	7.75
Plate 3	.00	.00	.00	.00	.00	2.96
Wrong plates:						
Plate 1	.00	.00	29.38	6.56	7.80	16.81
Plate 2	1.30	1.44	.36	6.91	15.18	3.18
Plate 3	5.61	3.13	8.84	16.22	10.29	11.58
Wrong direction	4.73	18.99	1.81	11.72	10.51	2.15
Irregular course	5.46	20.81	6.33	7.83	8.33	2.17
Climbing	8.16	15.88	6.66	2.67	5.36	3.31
Entrance door	15.74	12.08	15.26	3.72	.86	3.29
Inner door	28.34	9.54	11.64	6.90	16.86	5.43
Going around:						
Counterclockwise	3.01	2.64	.00	5.35	.86	2.80
Clockwise	1.49	3.08	.13	1.10	.00	.01
Running beyond	3.09	.00	.00	2.54	.00	.03
Miscellaneous	22.60	11.76	15.63	2.23	8.57	2.95
Total	100.00	100.00	100.00	100.00	100.00	100.00

the basis of number of trials to learn and not on the basis of number of errors. On Step II subject E made the poorest record and subject F fifth from the poorest. However, since neither of these was a representative case, due to their having been allowed to continue fixed habits over a long period of time, they were excluded from this comparison and subject B, which held the sixth place from the end, was used. Even with this shift, there was still a very large gap between the two groups. The number of trials for the poorest of the superior group was 15 and that for the best of the inferior group was 285. In Step III the two best monkeys were excluded because they made no errors at

all. Thus it was necessary to use the subjects ranking fifth and sixth. Nevertheless, the gap between the two groups was from 17 to 234 trials.

Table 18 shows that for Step I the error of running to or working at the inner door ranks first, and miscellaneous errors second, in average percentage distribution for the superior group. On the other hand, these errors take sixth and fifth places, respectively, for the inferior group. Errors of irregular course and wrong direction rank first and second respectively for the latter group, while for the superior group they rank sixth and seventh in relative frequency. That all four types of errors were relatively difficult to eliminate is indicated in Table 17 by rising trends.

It is not improbable that running to or working at the inner door, and miscellaneous errors, represent a more definite attack on the problem than irregular course and wrong direction. The latter may represent merely running around in the box.

On Step II one striking difference in the behavior of the two groups had to do with reactions to plate 1. The poorer learners were inclined to omit this plate and run directly to plate 2, while the better learners never omitted plate 1 but frequently repeated the reaction to plate 1 before going to plate 2.

Again on Step III the error of omitting plate 1 was of first importance for the inferior group, but relatively unimportant for the superior group. Table 17 also indicates that the omission of plate 1 was a troublesome error. The ascending trends which it displays for both Steps II and III indicate that it was one of the most

difficult to eliminate. The error of wrong plate 2, which in Step III shows the highest average percentage for the better group, is well toward the end of the list for the poorer group. This error, which consisted to a large extent in repeating plate 2 after it had once been touched, was evidently less serious since it showed little tendency to increase in relative frequency throughout the learning period.

It seems probable that to some extent the relative frequencies of certain types of errors were due to specific reaction tendencies peculiar to the individual monkeys. However, there is nothing conclusive in the data to support this. Nevertheless, it is evident that the predominating types of errors do differ for the two extreme groups. While the cases are too few to draw any definite conclusions, they suggest that the predominating types of errors may be of considerable significance.

SUMMARY

1. The study involved testing seventeen young rhesus monkeys in the Jenkins problem apparatus, which provides tasks of increasing complexity, without changing the type of motor response. The basic problem consisted of a series of three steps of increasing complexity.

2. All of the subjects met the required norm of mastery (nine perfect trials out of ten) on Steps I and II and all except one on Step III.

3. The learning scores (trials, errors, time) and also the original activity scores (plates depressed, quad-

rants traversed) were found to be extremely variable for the individual, and from step to step. This variability seemed to be due in the main to differences in tameness, in playfulness, in the formation of certain stereotyped errors of the position-habit type, in the occurrence of specific reaction tendencies, in the amount of transfer effect from one step to another, and in genuine individual differences in ability to learn.

4. Step I was clearly more difficult than either Steps II or III, as shown by the median scores in trials, errors, and time. Steps II and III appeared to be about equally difficult in terms of the same criteria. However, the individual records did not show perfect consistency throughout.

5. No very definite indication of sex differences was evident. Since one female failed to learn Step III and all of the males learned it, the males might be said to be superior. Furthermore, the males were more active as shown by the speed-of-activity scores (plates per minute, quadrants per minute). However, on the whole, the females made lower scores in trials and errors and in the quadrant-plate ratio.

6. Group learning curves were computed by a modification of the Vincent method. These curves (error, time) were typical learning curves, except that each of the curves for Step I shows an initial rise which may be associated with the first establishment of the habit of reacting to plates.

7. A progressive improvement in adjustment to the problem situation from step to step was indicated by

IV

THE ADVANCED PROBLEM

The advanced problem has already been described in a previous section on procedure and, as indicated, was a continuation of pattern behavior beyond the basic problem. It involved twenty steps, beginning with Step IV and ending with Step XXIII. As previously indicated, each subject was trained on a given step until he reached the required norm of mastery (nine perfect trials out of ten) and then was transferred to the next step. Each subject was advanced to successive steps until he reached his limit in ability to learn, i.e., failed to learn according to one of the criteria indicated in the section on procedure. The results presented will include learning and activity scores.

Learning Scores

The individual learning scores made by the thirteen monkeys on the various steps of the advanced problem are presented in Table 19. The measures of central tendency and of variability are shown in Table 20. The number of animals included in the data decreases step by step, as the monkeys failed to learn. Only the scores for those monkeys which learned a given step are included in the data for that step. Due to the decreasing number of subjects, the group data become less reliable as the problem becomes more complex.

Here, as in the basic problem, the median may be taken as a better measure of central tendency than the

TABLE 19

RESULTS OF ADVANCED PROBLEM SHOWING INDIVIDUAL LEARNING SCORES

Animals	Trials Total	Trials Failure	Trials Perfect	Errors, total	Minutes, total
			STEP IV		
Males					
A	245	19	25	1496	159.48
B	84	2	23	326	35.02
C	Failed				
D	Failed				
E	140	18	54	831	107.15
F	292	5	90	2000	159.93
G	57	6	6	371	41.78
Females					
S	Failed				
T	Failed				
U	1876	56	79	6027	713.00
V	264	27	61	1881	218.28
W	1174	4	138	5045	342.05
X	44	0	12	94	14.55
			STEP V		
Males					
A	108	0	41	175	27.27
B	329	0	94	890	89.28
E	89	4	17	437	50.05
F	91	0	37	223	20.77
G	225	4	43	779	80.50
Females					
U	Failed				
V	235	1	46	1015	111.62
W	Failed				
X	24	1	6	106	13.23
			STEP VI		
Males					
A	165	5	22	486	62.50
B	64	0	4	219	16.27
E	52	0	13	167	24.18
F	215	0	83	405	46.15
G	13	0	3	10	2.13
Females					
V	288	1	100	865	86.72
X	257	2	76	737	111.88
			STEP VII		
Males					
A	230	0	83	291	48.97
B	52	0	14	111	11.12
E	327	2	83	811	163.82
F	78	0	41	109	21.67
G	Failed				
Females					
V	17	0	1	35	3.00
X	200	1	90	185	55.42

TABLE 19 (*continued*)

Animals	Trials Total	Trials Failure	Trials Perfect	Errors, total	Minutes, total
			STEP VIII		
Males					
A	10	0	3	15	1.35
B	268	0	99	859	84.18
E	212	10	27	1310	171.80
F	14	0	8	17	5.90
Females					
V	116	1	22	495	51.08
X	158	1	36	313	65.55
			STEP IX		
Males					
A	140	0	78	163	22.90
B	100	0	17	342	32.03
E	626	0	31	2288	219.77
F	84	0	29	111	19.08
Females					
V	161	0	40	350	39.05
X	Failed				
			STEP X		
Males					
A	147	0	42	309	38.57
B	440	0	64	1802	172.17
E	88	1	42	267	41.97
F	Failed				
Females					
V	110	0	12	484	61.62
			STEP XI		
Males					
A	64	0	21	73	10.12
B	155	0	25	496	56.92
E	83	0	12	256	27.85
Females					
V	125	1	25	412	56.38
			STEP XII		
Males					
A	153	0	44	183	33.87
B	308	3	103	1341	154.55
E	358	0	106	1212	148.12
Females					
V	629	0	74	1991	250.42
			STEP XIII		
Males					
A	9	0	3	10	1.57
B & E	Failed				
Females					
V	164	0	21	404	42.65

TABLE 19 (*continued*)

Animals	Trials Total	Trials Failure	Trials Perfect	Errors, total	Minutes, total
		Step XIV			
Males					
A	215	0	44	287	46.23
Females					
V	*Failed*				
		Step XV			
Males					
A	151	0	54	203	36.00
		Step XVI			
A	140	0	50	137	29.73
		Step XVII			
A	378	0	123	827	111.10
		Step XVIII			
A	59	0	17	139	18.67
		Step XIX			
A	57	0	24	87	17.13
		Step XX			
A	453	7	104	2174	216.93
		Step XXI			
A	41	0	13	86	12.10
		Step XXII			
A	116	3	51	270	42.60
		Step XXIII			
A	Failed				

average. On the whole, the medians are somewhat smaller than the averages, showing that the extreme scores tend to be at the upper end of the range. Due to the small number of cases and the wide spread of the scores, the range and the quartile deviation are of greater significance than any of the other measures. The ranges and quartile deviations indicate great variability in the performance of the group on all of the steps.

The results obtained on Step IV are in general somewhat different from those obtained on the higher steps. For this reason the data on this step will be discussed

TABLE 20

Showing Measures of Central Tendency and Variability for Trials, Errors, and Minutes, in the Various Steps of the Advanced Problem*

	Median	Average	Range	Quartile deviation	Average deviation	Standard deviation	Coefficient of variation
			Step IV (9 animals)				
Trials	245.00	464.00	44-1876	110.63	364.56	596.92	128.65
Errors	1496.00	2007.89	94-6027	816.50	1481.22	2005.87	99.90
Minutes	159.48	199.03	14.55-713.00	83.49	137.20	206.07	103.54
			Step V (7 animals)				
Trials	108.00	157.29	24-329	77.38	83.57	99.54	63.28
Errors	437.00	517.86	106-1015	324.50	311.43	345.27	66.67
Minutes	50.05	56.10	13.23-111.62	31.91	31.45	35.32	62.96
			Step VI (7 animals)				
Trials	165.00	150.57	13-288	91.63	90.14	100.51	66.75
Errors	405.00	412.71	10-865	210.50	241.71	286.66	69.46
Minutes	46.15	49.98	2.13-111.88	27.91	31.22	36.73	73.49
			Step VII (6 animals)				
Trials	139.00	150.67	17-327	90.25	101.67	110.08	73.06
Errors	148.00	257.00	35-811	83.00	172.00	260.05	101.19
Minutes	33.32	50.67	3.00-163.82	22.57	38.74	54.02	106.61
			Step VIII (6 animals)				
Trials	137.00	129.67	10-268	86.50	83.00	95.40	73.57
Errors	404.00	501.50	15-1310	330.50	386.50	463.41	92.40
Minutes	58.32	63.31	1.35-171.80	35.62	43.87	57.00	90.03
			Step IX (5 animals)				
Trials	140.00	222.20	84-626	33.88	120.60	203.76	91.70
Errors	542.00	650.80	111-2288	112.00	472.80	824.09	126.63
Minutes	32.05	66.57	19.08-219.77	8.63	43.37	76.92	115.55

TABLE 20 (*continued*)

	Median	Average	Range	Quartile deviation	Average deviation	Standard deviation	Coefficient of variation
			STEP X (4 ANIMALS)				
Trials	128.50	196.25	88-440				
Errors	396.50	715.50	267-1802				
Minutes	51.80	78.58	38.57-172.17				
			STEP XI (4 ANIMALS)				
Trials	104.00	106.75	64-155				
Errors	334.00	309.25	73-496				
Minutes	42.12	37.82	10.12-56.92				
			STEP XII (4 ANIMALS)				
Trials	333.00	362.00	153-629				
Errors	1276.50	1181.75	183-1991				
Minutes	151.34	146.74	33.87-250.42				
			STEP XIII (2 ANIMALS)				
Trials	86.50	86.50	9-164				
Errors	207.00	207.00	10-404				
Minutes	22.11	22.11	1.57-42.65				

*Since only one animal learned Steps XIV to XXII, the data for these steps are not included in this table. See Table 19 for individual records.

more or less separately. As shown by Table 20, the individual trial scores on Step IV ranged from 44 to 1876, errors from 94 to 6027, and time from 14.55 to 713.00 minutes. However, this spread would be greatly reduced (trials 44 to 292, errors 94 to 2000, time 14.55 to 218.28) by the elimination of two extreme cases, subjects U and W. In both of these cases learning was retarded because of stereotyped errors of the position-habit type which were very difficult to eliminate. The former developed the habit of circling the inner cage before reacting to the plates. After efforts to break up this habit by means of delays had failed, it was decided to advance the animal to Step V as soon as she made nine trials out of ten in which only this one error occurred. It was hoped that the error would drop out when the monkey was introduced to a new step which involved a slightly different pattern. Subject W was handicapped on Step IV, as in the preceding steps, by the habit of darting out of the entrance compartment and passing plate I without touching it. This was caused apparently by being conditioned against the entrance door, as mentioned in the protocols. Both of the subjects made failure trials consistently almost from the beginning when transferred to Step V.

The results definitely indicate that Step IV was particularly difficult. This is shown by the fact that four of the thirteen monkeys trained on the step failed completely, and by the very large number of trials, errors, and minutes required to learn it. The median scores for trials, errors, and time were larger on this step than

on any other except for the trials score on Step XII. It might be argued that the median scores favored the higher steps because the slow learners were eliminated before they reached these stages. However, if only scores of the four subjects A, B, E, and V (all of which learned twelve steps) are included, the median scores are greater for these subjects on this step than on any other except Step XII. Step IV thus appeared to represent a critical stage in the mastery of the advanced problem.

As has already been indicated in the section on procedure, the first reversal of direction was introduced on Step IV. This obviously accounts for the extreme difficulty of the step. Three of the four monkeys which failed Step IV failed completely to learn the reversal part of the pattern. They repeatedly circled about the cage in a counterclockwise direction, depressing all of the plates again and again until, after many successive failures, they became inactive. However, the reversal act once learned did not appear to give particular difficulty at any other point. In no case was failure on another step due to failure to learn the reversal part of the pattern.

Individual learning curves (error, time) were calculated by the Vincent method. As a rule, on Step IV they were typical for sensory-motor problems, i.e., they started at the peak and descended more or less consistently to the end, indicating that the time and errors decreased fairly consistently throughout the learning period. Table 21 shows that 77.8 per cent of the error curves and 66.7 per cent of the time curves

TABLE 21

SHOWING THE DISTRIBUTION, THROUGHOUT THE VARIOUS TENTHS OF THE LEARNING PERIODS, OF THE PEAKS FOR INDIVIDUAL LEARNING CURVES ON THE ADVANCED PROBLEM

Curves	Tenths									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Error (Step IV)	77.8%	0.0%	11.1%	0.0%	0.0%	11.1%	0.0%	0.0%	0.0%	0.0%
Time (Step IV)	66.7	0.0	11.1	0.0	11.1	11.1	0.0	0.0	0.0	0.0
Error (Steps V to XXII)	24.4	11.4	6.8	14.2	12.3	9.2	5.6	5.6	8.6	1.9
Time (Steps V to XXII)	15.7	13.0	13.0	17.5	9.3	4.6	8.3	9.3	9.3	0.0

were of this type. In only 22.2 per cent of the error curves and 33.3 per cent of the time curves did the peaks occur later than the point representing the first tenth of the curve.

The learning curves (time, error) for all of the later steps were generally similar to each other. They differed markedly from those for Step IV in one important detail: the peaks came at some other point than at the beginning. As a rule, on these higher steps the monkeys started off fairly well when advanced to a new step and, therefore, the initial time and error scores were low. Somewhat later they began making a great many errors. The peaks of the curves (error, time) in such cases occurred at various later points, as shown in the last two arrays in Table 21. The data for this table were obtained by tabulating the position (tenth) at which the peak of each individual curve occurred. These were combined for all of the steps and are shown in the table in terms of percentages. Thus 24.4 per cent of the individual error curves for steps from V to XXII started at the peak. The remainder of the individual error curves started relatively low, 11.4 per cent of them reaching their peaks at the second tenth, 6.8 per cent at the third tenth. An even larger proportion of the curves reached their peaks on the fourth and fifth segments of the curves. In some cases the peaks of the curves came on the last tenth. In general, the peaks of the time curves occurred at points corresponding to those on the error curves. The data yield no definite explanation for this atypical feature of the curves. It was observed that in many instances the

monkeys became confused after having done very well on a given step, which led to a rise in the error and time scores. This type of response was neither peculiar to a given individual nor to a particular step.

As has already been indicated, differences in individual performance were very marked throughout all of the steps of the advanced problem. In general, the same factors which were discussed in connection with group variability on the basic problem should also be considered here. These factors were there divided into two classes, those which relate to the conditions and set-up of the experiment and those which relate to the individual characteristics of the subjects themselves. The former include a shift in the time limit for trials, the element of chance in regard to the first success, and the use of a high norm of mastery. The first of these factors would not apply here since the time limit for trials remained constant (three minutes) throughout the advanced problem. The element of chance seems to be relatively unimportant in the advanced problem since the subjects had already learned to react to plates by the time they were introduced to these steps. With regard to the high norm used, the analysis made on the basic steps would indicate that this factor had no definite influence upon group variability. Such analysis beyond the basic problem was scarcely feasible, since only the high norm had actually been used throughout and the computation of the lower norms would, therefore, become less meaningful as the steps progressed.

The second class of factors, which relate to charac-

teristics of the subjects, are; differences in tameness, in playfulness, in age, in the formation of certain stereotyped errors of the position-habit type, in the occurrence of specific reaction tendencies, in the amount of transfer effect from step to step, and in genuine individual differences in ability to learn. With regard to tameness, while there did seem to be fundamental differences, the actual variation in tameness was somewhat reduced by the time the advanced problem was begun. At this stage in the experiment practically all of the subjects had made very satisfactory adjustments to the entire experimental situation. It would seem, therefore, that differences in tameness were relatively unimportant in relation to the results on the advanced steps. Differences in degree of playfulness also became relatively less pronounced on the advanced steps. For example, subject A, which was the most frolicsome of all of the subjects during training on the basic problem, became a very consistent worker on the advanced problem. Subject B also became less playful as the experiment progressed. On the other hand, subject V developed a slightly greater tendency to playfulness as the steps became more complex. None of the other subjects trained on the advanced problem displayed any great tendency to play in the apparatus.

Age differences would seem to be of less significance for the advanced problem than for the basic problem, since the subjects were approaching each other in maturity so far as growth and intelligence are concerned. Moreover, there seems to be no evidence that the older subjects were superior to the younger subjects. For

example, the three oldest (largest) subjects failed Step IV completely, while one of the youngest subjects made the best record on this step. On Step V both the poorest record and the best record were made by young monkeys. On Step VI the best record was made by the monkey which ranked midway in the group as to age. The poorest record on this step was made by one of the youngest monkeys.

The development of stereotyped errors of the position-habit type scarcely ever occurred on the advanced problem except in the two cases already mentioned in connection with Step IV. These errors did contribute to variability on this step but this factor was not significant on the later steps.

Specific reaction tendencies characteristic of the individual animal probably played an important part in determining the scores. This would seem to be indicated by the fact that the relative difficulty of the several steps shifted about for the various animals. An exception can be made in the case of Step IV, which ranked very high in difficulty for nearly all of the animals. It might be supposed that steps which ended on plate 2 at the back of the box would be especially difficult, since they involved passing either plate 1 or plate 3 without touching it. It might also be thought that as the problem increased in complexity the error and time scores would be higher. As a matter of fact, however, there seems to be no consistent trend of any sort running through the series. For example, a given animal might make a low score on one step, a high score on the next, and a low on the next, etc.

It seems likely that the inconsistency from animal to animal and from step to step was related more or less directly to reaction tendencies characteristic of the individual monkeys. The data seem to supply no definite evidence as to what these tendencies were. Whether they were due to hereditary differences or whether they arose from the peculiar situations in the apparatus cannot be determined.

It is not unlikely that differences in transfer effects may have been of considerable importance. This factor is associated with the lack of consistency in the scores of the same animal from step to step. Sometimes a high score on one step was followed by a low score on the next and this in turn by a high score on the next. In other cases low scores on two steps might be followed by a high score on the next. High scores in such cases as here cited were often associated with the final stage in reaching the high norm of mastery. This would seem to involve a degree of overlearning beyond the average on all points of the pattern up to that point. It would seem that the effect of this overlearning might well transfer to the next step, resulting in a low score for that step. On the other hand, a low score should be unfavorable in terms of transfer so far as the next step was concerned. The extent to which such transfer effects may have operated to determine differences in scores from step to step cannot be determined from the data. Even if the explanation be accepted, it cannot be applied to all scores, since no consistent alternation of high and low scores occurred throughout.

By way of summarizing the various points in regard to group variability, it would seem that none of the factors relating to the set-up of the experiment were of much significance in determining differences in individual scores. Moreover, such factors as differences in tameness, playfulness, and age were relatively unimportant. The formation of certain stereotyped errors could have been of significance only on Step IV, since they scarcely occurred at all on any other step. Differences in specific reaction tendencies and in the amount of transfer from step to step may have been somewhat influential in determining differences in the individual scores. However, it seems that to a large extent these differences were due to genuine individual differences in ability to learn.

As stated in a preceding section, the chief aim of the study was to determine the limits of learning for the experimental group. Each animal was advanced step by step until it finally failed completely to learn a given step according to one of the criteria discussed in the section on procedure. The final step learned by a given monkey was taken as the limit of ability for that individual, since the animal failed on the next step. There were in general three different types of failures: those in which the monkeys failed almost at once upon being introduced to the new step, i.e., those in which they consistently made failure trials and soon became inactive, as in the cases of subjects C, D, S, U, and W; those in which they made considerable progress in learning and then failed, due to a more or less gradual disintegration of the habit to the point where

they consistently made failure trials, as in the cases of A, F, and V; and those in which they made progress in learning and were nearly always successful in obtaining the reward but never succeeded in eliminating certain errors.

The data for limits of learning are presented in Table 22. This table indicates the number of animals

TABLE 22

SHOWING THE NUMBER OF MONKEYS WHICH REACHED THE LIMITS OF LEARNING ON THE VARIOUS STEPS

Steps	Males	Females	Combined
	BASIC PROBLEM		
II		1	1
III	2	2	4
	ADVANCED PROBLEM		
IV		2	2
VI	1		1
VIII		1	1
IX	1		1
XII	2		2
XIII		1	1
XXII	1		1
Totals	7	7	14

which reached the limits on the various steps. As will be seen, the total group ranged in limits from 2 to 22 steps. The median number of steps learned was 5 and the average was 7.4. A comparison of males and females distinctly favors the males, which have a median score of 9 steps, or more than twice that of the females. The males also show a much wider range than do the females. The range is greatly increased by subject A, which learned 9 steps more than any other monkey and 10 steps more than any other male. A comparison in terms of overlapping shows

that only 14.29 per cent of the females reached or exceeded the median of the males.

In connection with limits of learning, the question again arises as to the causes underlying differences in performance. Factors which may have affected differences in the facility with which the various steps were learned have already been discussed. Some of these factors may have affected to some extent the limits of learning in certain cases. However, each subject was given ample time to learn the several steps, and motivation was kept at a relatively high level in all cases. It seems, therefore, that in the main the differences in number of steps learned represent genuine individual differences in ability to learn.

The results do not show any definite relationship between number of steps learned and the speed at which they were learned in terms of total number of trials. A negative correlation ($-.27 \pm .18$) was found between number of trials required to learn the basic problem and limits of learning. Such a correlation, especially when based upon very few cases, is of little significance except perhaps to indicate that there is probably little if any relationship between learning the basic problem quickly and a high level of ability. In the advanced problem, a correlation was computed for the six subjects which continued through Step VIII. The six subjects were ranked in order of merit from one to six on each of the five steps (IV to VIII inclusive). The average rank of each was obtained and a correlation computed between these average rankings and the rankings for these subjects on the

basis of limits of learning. Again no significant correlation (—.10±.03) was obtained. Such evidence seems to suggest that two different types of functions were measured by scores in number of trials and by scores in number of steps. These would seem to be somewhat analogous to speed and power as measured by various tests in human work. The number of trials required to learn the several steps roughly represents speed of learning at a given level, while the number of steps learned represent the final level of ability. This is corroborated to some extent by the work of Riess on rats and guinea pigs (25). He found that guinea pigs were unable to master Step II, while rats succeeded in doing so. However, the guinea pigs learned Step I with fewer trials than did the rats. Moreover, it is in harmony with the general accepted principle that complex tasks are more effective than simple tasks in bringing out individual differences in learning capacity.

It might be expected that, after a number of steps had been mastered, the subjects would develop a generalized habit of adding another plate to the pattern. This would be indicated by low scores on all succeeding steps. As a matter of fact, none of the animals in the advanced problem passed directly from one step to another without making errors. In the basic problem two such instances did occur in passing from Step II to Step III. In the advanced problem there were four cases in which the task of adding a plate was learned in 10 trials or less, and four other cases in which it was learned in 20 trials or less. Since the

total number of steps learned by all animals in the advanced problem was 63, it will be seen how infrequently "sudden" learning occurred. It seems likely that all of these cases can be accounted for in terms of transfer of training. They certainly do not represent "insight" on the rational level since the animals in every case made very high scores on later steps. The latter should not have happened if the animals had developed a generalized solution to the problem.

It should be pointed out in this connection that there was actually little opportunity for the subjects to develop a generalized solution to the various steps. In the first place, the only signal which might have indicated to the monkey that it was being introduced to a new step was the failure of the door to open when the animal came to the end of the series. However, this could scarcely have been used as a signal, since for every instance in which it indicated the beginning of a new step there were probably fifty or more instances in which it indicated merely that the subject had made an error. The particular situation with reference to the latter case has been fully described in the preceding section in connection with corrected trials.

Activity Scores

The activity data on the advanced problem can conveniently be divided into four groups: (1) scores obtained directly from the original data; (2) scores which were computed from original time and activity scores; (3) an analysis of errors into various classes; and (4) an analysis of patterned behavior. The first three groups correspond directly to the three groups

discussed in connection with the basic problem. The fourth group applies only to the advanced problem and will be described in some detail below. These four groups will be taken up in order. Finally there will be a brief discussion of the relationship between the activity scores and final failure of the monkeys on the various steps.

The first group of activity data (number of plates depressed, number of quadrants traversed) for the individual animals is shown in the second and third columns of Table 23. The corresponding group

TABLE 23

RESULTS OF ADVANCED PROBLEM SHOWING INDIVIDUAL ACTIVITY SCORES

Animals	Plates depressed	Quadrants traversed	Quadrants per plate	Plates per minute	Quadrants per minute
		STEP IV			
Males					
A	2587	4006	1.55	16.22	25.12
B	860	1158	1.35	24.56	33.07
C	Failed				
D	Failed				
E	1497	1630	1.09	13.97	15.21
F	4236	5029	1.19	26.49	31.45
G	666	795	1.19	15.94	19.03
Females					
S	Failed				
T	Failed				
U	14431	23197	1.61	20.24	32.53
V	2981	3715	1.25	13.66	17.02
W	9946	16652	1.67	29.08	48.68
X	349	408	1.17	23.99	28.04
		STEP V			
Males					
A	831	1015	1.22	30.47	37.22
B	3603	4347	1.21	40.36	48.69
E	1018	1136	1.12	20.34	22.70
F	793	921	1.16	38.18	44.34
G	2695	3088	1.15	33.48	38.36
Females					
U	Failed				
V	3346	3766	1.13	29.98	33.74
W	Failed				
X	213	235	1.10	16.10	17.76

TABLE 23 (*continued*)

Animals	Plates depressed	Quadrants traversed	Quadrants per plate	Plates per minute	Quadrants per minute
			STEP VI		
Males					
A	1783	2401	1.35	28.53	38.42
B	602	802	1.33	37.00	49.29
E	694	752	1.08	28.70	31.10
F	2035	2209	1.09	44.10	47.87
G	90	96	1.07	42.25	45.07
Females					
V	3177	3510	1.10	36.64	40.48
X	2634	2739	1.04	23.34	24.48
			STEP VII		
Males					
A	2246	2618	1.17	45.86	53.46
B	508	631	1.24	45.68	56.74
E	3918	4284	1.09	24.04	26.15
F	905	968	1.07	41.76	44.67
G	Failed				
Females					
V	147	150	1.02	49.00	50.00
X	1774	1923	1.08	32.01	34.70
			STEP VIII		
Males					
A	88	86	.98	65.19	63.70
B	3627	4504	1.24	43.09	53.50
E	3913	4335	1.11	22.78	25.23
F	143	157	1.10	24.24	26.61
Females					
V	1776	1899	1.07	34.77	37.18
X	1703	1843	1.08	25.98	28.12
			STEP IX		
Males					
A	1455	1595	1.10	63.54	69.65
B	1505	1716	1.14	46.99	53.57
E	8619	9727	1.13	39.22	44.26
F	908	956	1.05	47.59	50.10
Females					
V	1912	2015	1.05	48.96	51.60
X	Failed				
			STEP X		
Males					
A	2269	2411	1.06	58.83	62.51
B	7169	8772	1.22	41.64	50.95
E	1521	1632	1.07	36.24	38.88
F	Failed				
Females					
V	1867	2095	1.12	30.30	34.00

TABLE 23 (*continued*)

Animals	Plates depressed	Quadrants traversed	Quadrants per plate	Plates per minute	Quadrants per minute
		STEP XI			
Males					
A	773	785	1.02	76.38	77.57
B	2039	2590	1.27	35.82	45.50
E	1202	1265	1.05	43.16	45.42
Females					
V	2052	2241	1.09	36.40	39.75
		STEP XII			
Males					
A	2352	2468	1.05	69.44	72.87
B	5384	6664	1.24	34.84	43.12
E	6173	6512	1.05	41.68	43.96
Females					
V	10485	11351	1.08	41.87	45.33
		STEP XIII			
Males					
A	136	146	1.07	86.62	92.99
B & E	Failed				
Females					
V	2587	2703	1.04	60.66	63.38
		STEP XIV			
Males					
A	3480	3745	1.08	75.28	81.01
Females					
V	Failed				
		STEP XV			
Males					
A	2400	2451	1.02	66.67	68.08
		STEP XVI			
A	2272	2289	1.01	76.42	76.99
		STEP XVII			
A	7854	8151	1.04	73.99	76.79
		STEP XVIII			
A	1342	1370	1.02	71.88	73.38
		STEP XIX			
A	1175	1192	1.01	68.59	69.59
		STEP XX			
A	13309	14256	1.07	61.35	65.72
		STEP XXI			
A	896	912	1.02	74.05	75.37
		STEP XXII			
A	3007	3066	1.02	70.59	71.97
		STEP XXIII			
A	Failed				

TABLE 25

SHOWING THE DISTRIBUTION, THROUGHOUT THE VARIOUS TENTHS OF THE LEARNING PERIODS, OF THE PEAKS FOR INDIVIDUAL ACTIVITY CURVES (PLATES DEPRESSED, QUADRANTS TRAVERSED) ON THE ADVANCED PROBLEM

Curves	Tenths									
	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Plates (Step IV)	66.7%	0.0%	11.1%	0.0%	11.1%	11.1%	0.0%	0.0%	0.0%	0.0%
Quadrants (Step IV)	77.8	0.0	11.1	0.0	0.0	11.1	0.0	0.0	0.0	0.0
Plates (Steps V to XXII)	13.6	12.9	6.2	20.4	11.7	5.6	7.4	5.6	12.9	3.7
Quadrants (Steps V to XXII)	13.6	16.7	8.0	16.6	14.5	4.6	5.6	1.9	14.8	3.7

been discussed in connection with the basic problem. The quadrant-plate relationship gives a fairly accurate measure of the proportion of activity which was directed toward the plates. It will be remembered that a perfect score on any step was 1.00. The number of plates per minute and the number of quadrants per minute are speed-of-activity scores and, to a large degree, on the advanced problem, represent the rate of running in the apparatus. All of these computed scores indicate, in some measure, the degree of adjustment to the problem situation.

The individual scores for this second group are presented in the fourth, fifth, and sixth columns of Table 23. The corresponding measures of central tendency and of variability for the group are shown in Table 26. The group scores indicate that beginning with Step IV the measures of central tendency show a general trend toward improvement in the quadrant-plate ratio through Step VIII, and in the speed-of-activity scores through Step IX. Since it seemed quite likely that such improvement was greatly affected by the dropping-out of the poorer monkeys, averages were calculated from Steps IV to XII, inclusive, for the four monkeys which learned the twelve steps. These averages indicate that for the four monkeys improvement did occur from step to step, except for a slight exception on Step VI through Step VIII in the quadrant-plate ratio and a definite increase in speed of activity through Step IX. The difference in speed of activity may, to some extent, be due to the possibility of acquiring more momentum on the slight-

TABLE 26

SHOWING MEASURES OF CENTRAL TENDENCY AND VARIABILITY FOR NUMBER OF QUADRANTS PER PLATE, NUMBER OF PLATES DEPRESSED PER MINUTE, AND NUMBER OF QUADRANTS TRAVERSED PER MINUTE*

	Median	Average	Range	Quartile deviation	Average deviation	Standard deviation	Coefficient of variation
		STEP IV (9 ANIMALS)					
Number of quadrants per plate	1.25	1.34	1.09- 1.67	.16	.17	.20	14.93
Number of plates per minute	20.24	20.46	13.66-29.08	4.98	4.93	5.44	26.59
Number of quadrants per minute	28.04	27.79	15.21-48.68	7.37	7.71	9.77	35.16
		STEP V (7 ANIMALS)					
Number of quadrants per plate	1.15	1.16	1.10- 1.22	.03	.03	.04	3.45
Number of plates per minute	30.47	29.84	16.10-40.36	7.69	6.51	8.22	27.55
Number of quadrants per minute	37.22	34.69	17.76-48.69	9.20	8.17	10.28	29.63
		STEP VI (7 ANIMALS)					
Number of quadrants per plate	1.09	1.15	1.04- 1.35	.05	.08	.12	10.43
Number of plates per minute	36.64	34.39	23.54-44.10	5.52	6.08	7.10	20.65
Number of quadrants per minute	40.48	39.53	24.48-49.29	8.16	6.89	8.41	21.27
		STEP VII (6 ANIMALS)					
Number of quadrants per plate	1.09	1.11	1.02- 1.24	.04	.06	.07	6.31
Number of plates per minute	43.72	39.73	24.04-49.00	8.87	7.12	8.84	22.25
Number of quadrants per minute	47.34	44.29	26.15-56.74	10.65	9.11	10.75	24.27
		STEP VIII (6 ANIMALS)					
Number of quadrants per plate	1.09	1.10	.98- 1.24	.04	.05	.08	7.27
Number of plates per minute	30.38	36.01	22.78-65.19	7.71	11.68	14.82	41.16
Number of quadrants per minute	32.65	39.06	25.25-63.70	9.71	12.40	14.64	37.48
		STEP IX (5 ANIMALS)					
Number of quadrants per plate	1.10	1.09	1.05- 1.14	.04	.03	.04	3.67
Number of plates per minute	47.59	49.26	39.22-63.54	5.75	5.26	7.91	16.06
Number of quadrants per minute	51.60	53.84	44.26-69.65	3.68	5.77	8.49	15.77
		STEP X (4 ANIMALS)					
Number of quadrants per plate	1.10	1.12	1.06- 1.22				
Number of plates per minute	38.94	41.75	30.30-58.83				
Number of quadrants per minute	44.92	46.59	34.00-62.51				

*Since only one animal learned Steps XIV to XXII, the data for these steps are not included in this table. See Table 25 for individual records.

TABLE 26 (*continued*)

	Median	Average	Range	Quartile deviation	Average deviation	Standard deviation	Coefficient of variation
		STEP XI (4 ANIMALS)					
Number of quadrants per plate	1.07	1.11	1.02- 1.27				
Number of plates per minute	39.78	47.94	35.82-76.38				
Number of quadrants per minute	45.46	52.06	39.75-77.57				
		STEP XII (4 ANIMALS)					
Number of quadrants per plate	1.07	1.11	1.05- 1.24				
Number of plates per minute	41.78	46.96	34.84-69.44				
Number of quadrants per minute	44.65	51.32	43.12-72.87				
		STEP XIII (2 ANIMALS)					
Number of quadrants per plate	1.06	1.06	1.04- 1.07				
Number of plates per minute	73.64	73.64	60.66-86.62				
Number of quadrants per minute	78.19	78.19	63.38-92.99				

ly longer steps. However, the gradual speeding-up, together with the improvement in the quadrant-per-plate scores, seems to indicate that the monkeys were still making some slight improvements in their adjustment to the problem on these earlier steps. A comparison of Table 24 with Table 26 shows that, while the group varies greatly from individual to individual with regard to the number of plates depressed and the number of quadrants traversed on the several steps, such variations were much smaller for the speed-of-activity scores and relatively slight for the quadrant-plate ratio. This together with the fact that marked differences from individual to individual were found in the learning scores shows that, while the monkeys differed enormously among themselves with regard to rate of learning the advanced steps, they differed relatively little in their adjustment to the problem situation. Furthermore, while the learning scores and original activity scores varied greatly from step to step for the given individuals, such differences were found to be relatively small with regard to quadrants-per-plate and speed-of-activity scores. To some extent the two latter tend to be systematic differences showing gradual improvement from step to step. If, as was suggested in the preceding section, lack of uniformity in the scores for a given individual from step to step was due in part to differences in transfer effects, the data seem to indicate that transfer was more uniform with regard to the general method of attacking the problem than with regard to other factors in the learning process.

Individual curves for the quadrant-plate ratio and speed of activity were computed by the Vincent method on each of the various steps. It was found that, with these as with the learning and the general activity curves, the point representing the poorest performance tended to appear at some tenth other than the first. The percentage distribution of these points is presented in Table 27. It will be noticed that the first two arrays represent peaks while the last four represent low points. Obviously the poor performances with regard to number of quadrants per plate give high scores, while the poor performances in speed of activity (plates per minute, quadrants per minute) give low scores. A comparison of this table with Tables 21 and 25 shows that here the curves on Step IV tend to display the same characteristic to a much greater degree than did the learning curves or the general activity curves.

The *third group of data* (*analysis of errors*) involved eighteen classes of errors. The various types of errors on the advanced problem were, in general, similar to those on the basic problem, a description of which will be found on pages 467-468. In addition to these there were errors of hesitation on the several plates (plates 1, 2, and 3). Such errors were relatively unimportant on the basic problem and when they did occur were classed as miscellaneous errors. However, as the series lengthened, these errors became more and more significant. On steps where it was necessary to touch off a given plate more than once to complete the series, it frequently happened that a

TABLE 27

SHOWING THE DISTRIBUTION, THROUGHOUT THE VARIOUS TENTHS OF THE LEARNING PERIODS, OF THE POINTS WHICH REPRESENT THE POOREST SCORES ON INDIVIDUAL ACTIVITY CURVES (QUADRANTS PER PLATE, PLATES PER MINUTE, QUADRANTS PER MINUTE) ON THE ADVANCED PROBLEM

Curves	Tenths 1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
					PEAKS					
Quadrants per plate (Step IV)	33.4%	11.1%	22.2%	0.0%	11.1%	0.0%	0.0%	0.0%	11.1%	11.1%
Quadrants per plate (Steps V to XXII)	14.1	12.9	10.2	9.5	8.6	12.3	9.5	9.5	10.4	3.0
					LOW POINTS					
Plates per minute (Step IV)	55.6	11.1	0.0	0.0	22.2	11.1	0.0	0.0	0.0	0.0
Quadrants per minute (Step IV)	55.6	11.1	11.1	0.0	11.1	0.0	0.0	11.1	0.0	0.0
Plates per minute (Steps V to XXII)	16.7	12.9	14.8	14.8	5.6	5.6	14.8	9.2	5.6	0.0
Quadrants per minute (Steps V to XXII)	18.5	9.2	12.9	16.7	9.3	1.9	11.1	7.4	7.4	5.6

subject would hesitate and look at the door each time it touched the plate which finally ended the series. For example, on Step IX, which ended with plate 1, it was necessary to react to plate 1 three times during the series. There was seldom any hesitation the first time it was touched, but a very frequent and significant error consisted in hesitation on plate 1 the second time it was touched in the series. Another important type of hesitation error often occurred for a time after the monkey was transferred to a new step. This was the tendency to hesitate on the final plate for the preceding step. More attention will be given to this hesitation behavior in connection with the development of the patterns.

The percentage distribution of the various types of errors on the several steps is shown in Table 28. The data for this table were compiled in exactly the same way as that for Table 16 on the basic problem. First, the number of errors falling in the various classes was found for the individual monkeys on each step. These scores were then converted into percentages of the total errors made on the step by the respective subjects. The individual percentage scores were then combined and averaged to obtain the group scores for each step as presented in the table. It will be noticed that the number of subjects gradually diminishes until, on the last nine steps, only one animal is represented.

The table indicates that throughout the entire advanced problem the emphasis tends to be on two general types of errors, reacting to the wrong plates and hesitating on plates. The highest percentage fre-

TABLE 28

TYPES OF ERRORS, SHOWING THE DISTRIBUTION OF EACH ON THE SEVERAL STEPS OF THE ADVANCED PROBLEM

Steps→ Number of animals→	IV (9)	V (7)	VI (7)	VII (6)	VIII (6)	IX (5)	X (4)	XI (4)	XII (4)	XIII (2)
Types of errors										
Omission of places:										
Plate 1	8.18%	8.39%	7.80%	13.99%	9.97%	8.47%	10.10%	6.77%	12.44%	23.57%
Plate 2	3.45	12.72	7.51	7.83	4.65	8.99	4.84	1.70	2.47	.62
Plate 3	1.92	.94	2.20	2.23	.70	.55	2.02	1.21	.37	.00
Wrong places:										
Plate 1	17.58	15.06	25.43	18.01	6.09	7.08	6.68	6.86	4.88	2.85
Plate 2	5.70	4.59	2.76	3.50	3.62	1.58	2.43	1.23	1.46	5.13
Plate 3	21.68	17.24	10.26	9.60	13.81	4.60	5.34	6.40	7.22	.37
Wrong direction	12.24	9.98	6.73	1.96	5.56	1.41	4.62	.69	2.89	5.25
Hesitation on places:										
Plate 1	1.83	6.60	7.93	2.04	4.15	30.34	11.62	3.86	4.27	13.61
Plate 2	6.86	3.48	7.04	15.01	20.26	6.82	24.16	18.55	21.99	1.24
Plate 3	2.25	1.89	2.37	9.92	8.79	1.34	3.57	31.07	6.17	.00
Irregular course	3.93	2.47	1.96	3.89	5.72	7.12	5.36	2.18	5.76	7.73
Climbing	2.87	2.49	1.08	.43	3.21	1.30	2.33	1.87	2.20	.13
Entrance door	4.17	3.32	2.51	3.38	2.78	2.24	4.86	4.17	7.62	13.12
Inner door	3.38	8.86	6.44	5.01	6.73	15.80	6.96	4.65	8.25	19.02
Going around:										
Counterclockwise	3.07	1.05	2.56	2.79	1.95	.29	1.75	2.79	2.40	.00
Clockwise	.25	.06	.00	.00	.43	.76	1.70	2.62	1.90	.13
Running beyond	.00	.28	5.12	.02	1.44	1.25	1.47	3.32	7.60	7.23
Miscellaneous	.66	.58	.30	.39	.14	.06	.19	.06	.11	.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

TABLE 28 (*continued*)

Steps→ Number of animals→	XIV (1)	XV (1)	XVI (1)	XVII (1)	XVIII (1)	XIX (1)	XX (1)	XXI (1)	XXII (1)
Types of errors									
Omission of plates:									
Plate 1	23.32%	6.40%	6.57%	13.91%	5.76%	3.45%	3.96%	3.49%	.74%
Plate 2	2.09	13.30	.00	2.18	1.44	4.60	.28	.00	1.48
Plate 3	2.09	.49	.73	.00	.00	.00	.09	.00	.00
Wrong plates:									
Plate 1	26.46	5.91	.73	1.69	4.32	10.34	1.38	3.49	.00
Plate 2	2.79	.99	.73	1.33	.00	.00	.64	.00	1.48
Plate 3	6.61	5.42	2.19	5.99	2.88	3.45	20.10	22.09	17.04
Wrong direction	1.39	.99	2.19	.60	.00	.00	.41	.00	1.85
Hesitation on plates:									
Plate 1	5.91	5.91	16.06	51.76	69.04	33.33	15.46	16.28	16.30
Plate 2	9.05	13.79	.73	.85	4.32	3.45	31.69	34.89	22.23
Plate 3	1.15	45.35	13.87	4.72	2.16	33.33	6.03	4.65	8.89
Irregular course	2.44	.00	2.19	5.44	1.44	.00	1.84	1.16	2.22
Climbing	3.82	.00	1.46	.36	.00	.00	.55	.00	.37
Entrance door	.35	.00	1.46	1.33	4.32	1.15	2.02	.00	1.85
Inner door	6.61	.99	2.19	11.12	1.44	1.15	5.29	13.95	14.07
Going around:									
Counterclockwise	1.39	.00	.00	.12	.00	.00	.00	.00	.00
Clockwise	.00	.00	.00	.12	.00	.00	.00	.00	.00
Running beyond	3.48	2.46	48.90	.48	2.88	5.75	10.26	.00	11.48
Miscellaneous	1.05	.00	.00	.00	.00	.00	.00	.00	.00
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

quency for each step falls under one of these main classes, with the exceptions of Step XIII, where it occurs on *omission of plate 1,* and Step XVI, where it occurs on *running beyond.* The wrong plate reactions tend to predominate on the earlier steps (Steps IV to VII inclusive), while the hesitating type of errors tend to predominate on Step VIII and thereafter.

A study was made of the individual scores to determine whether the average scores were really representative of the group. It was found that, with the exception of Step VII, the type of error taking first rank for the group on each step ranked very high in frequency for practically all of the subjects. On this step the monkeys differed markedly among themselves as to the predominating type of error. It appears, therefore, that in large part the most frequent types of errors made on the advanced problem were deter*mined by the task itself.*

The fourth division of the data (development of patterns) seemed to be of greater significance than the types of errors. A record was obtained, from the original data, of the pattern of behavior on each trial from the time the subject entered the reaction compartment until he completely broke off the pattern by running to the front of the cage or by turning back on a wrong plate. In other words, for this purpose, only records of what the subject did at the beginning of the trial were included. Various corrections made later were not used in the study of patterns because the pattern frequently became ex-

tremely complicated when the complete trial was taken into account. For example, on a given trial on Step V where the correct response is plates 1, 2, 3 reverse to 2, 1, the animal might run through the series 1, 2, 3 reverse to 2 and go directly to the inner door. This would constitute a breaking-off of the pattern before the completion of the series and, although the animal was required to correct his error before obtaining the food, *for the purpose of pattern analysis* no attention was given to the performance after the breaking-off of the pattern. In many cases the total pattern was completed before being broken off, although hesitations, or omissions of plates, or both, may have occurred along the way. In such cases the total pattern was used but not the corrected part. For instance, if the monkey working on Step V ran through the series 1, 2, 3 reverse to 1, he would have completed the total pattern and this much of the record would be used in the analysis. However, the subject omitted the fourth plate in the series (plate 2) and, of course, was required to correct that error before he could obtain the food.

An analysis of the data indicated that the development of the pattern on each step was characterized by certain fairly definite stages. It was not possible to combine the data for the several subjects on a given step since these stages tended to emerge at different points in the learning period for the various animals. For this reason, the data can best be presented by giving illustrations of specific cases. Step IV will be discussed separately since it involved the introduction

of a new element into the pattern (reversal of direction).

The reversal pattern used in Step IV was found to be relatively difficult. Of the nine subjects which learned this step, only one learned the reversal part of the pattern immediately. The usual behavior during the first few trials consisted of continuing around the cage in a counterclockwise direction, stepping on the plates in order, that is, 1, 2, 3, 1, 2, 3, etc. This stage represented the carrying-over of the pattern from Step III without the addition of the reversal. The second stage was characterized, as a rule, by the completion of the total pattern including the reversal of direction to plate 2, but omitting plate 1 at the beginning of the series (plates 2, 3 reverse to 2). It will be noticed that at this stage the monkeys were going directly to the plate which finished the series. In the cases of four subjects, an antagonistic pattern of starting in a clockwise direction (the direction in which the series ended) developed at some time during the learning process. All of these patterns seem to be natural methods of attacking the problem. The first is merely a continuation of the preceding step, the second is reacting first to the plate which "seemed" to be the effective one in preceding trials on the step, and the third is "trying out" a short cut by reacting to the final plate from the direction which proved successful in previous trials. The final stage in pattern development on this step was characterized by the perfection of the total pattern. The monkeys varied considerably as to the relative proportion of the learning period given to each of these stages.

The remaining steps (V to XXII inclusive) can best be discussed together with the use of typical examples. In general, the development of patterns on these steps tended to show three stages. The first stage was characterized by a complete breaking-off of the pattern on the next to the last plate of the series (the plate on which the preceding step ended), or a hesitation on that plate. On the simpler steps (V and VI) this stage usually took the form of a complete breaking-off of the pattern at this point. On the later steps it more often took the form of hesitating on the plate and then running to the final plate, thus completing the series. This first stage usually lasted for only a few trials. However, in two cases it continued practically throughout the entire learning period. The behavior of monkey V, when first transferred to Step V, is a typical example of the first stage in pattern development. The correct response on this step was plates 1, 2, 3 reverse to 2, 1. In nine out of the first ten trials on the step, monkey V reacted to the series 1, 2, 3 reverse to 2 and then broke off the pattern at this point by running directly to the inner door. This same monkey when introduced to Step X displayed the hesitating type of behavior instead of completely breaking off the pattern at the next to the last plate. In the first nine trials she ran through the series 1, 2, 3 reverse to 2, 1 reverse to 2, 1, hesitated and then reversed to 2, thus completing the series.

The typical second stage was characterized by a breaking-down of the pattern into smaller units. In

some cases, however, the pattern was completely broken off at these points, and in others there was merely a hesitation on the plate and then a continuing of the pattern. These smaller units or partial patterns were determined primarily by the larger pattern, but to some extent they differed from individual to individual on a given step. For example, on Step VI in which the correct pattern was 1, 2, 3 reverse to 2, 1 reverse to 2, the partial pattern most frequently developed consisted in merely depressing the first two plates. At this point the subject broke up the pattern by turning back to the door or to plate 1. However, two of the monkeys developed the partial pattern 1, 2, 3 reverse to 2 and then broke off without completing the series. As the length of the series increased, there was a definite tendency for the partial patterns to be units which ended on the final plate of the series. For example, on Step VII, where the series ended with plate 3, the pattern was frequently broken by a hesitation on plate 3 the first time it was reacted to. Thus the total pattern was broken up into the units 1, 2, 3 and 2, 1, 2, 3. On the higher steps it was noticed that frequently the total pattern was broken up into a series of partial patterns. For instance, on Step XVII, subject A nearly always completed the entire series but soon developed the habit of hesitation on the thirteenth plate of the series. In addition he frequently hesitated on the fifth and ninth plates. In other words, there was a slight tendency to hesitate on plate 1 each time it was depressed.

The third stage was represented by the more or less

gradual organization of these smaller units into a single larger unit which led to the perfection of the total pattern. Although it is possible to speak of these three stages, there was not always a clear-cut dividing line between them. The first stage was frequently quite clear cut, the second stage (development of smaller units) scarcely appearing at all until the first had disappeared. Often a number of perfect trials intervened before the breakdown into smaller units. There was much overlapping of the second and third stages. The first stage failed to appear in only 2 cases out of 54, and the second stage in only 5 cases. The latter were all cases in which the step was learned in less than 25 trials. In one instance in which the step was learned in as few as 10 trials the second stage did appear. Obviously the third stage always developed on steps which were learned.

One very interesting phenomenon which was closely related to the breaking-up of the pattern into a series of smaller units was that of rhythm or grouping of the plates. This was observed to some extent in subject V on Step XIII, but was much more striking on the higher steps with subject A. Both of these monkeys ran very rapidly and on perfect trials there seemed to be a definite grouping of the plates into series of fours. There was no break in the pattern in the sense of there being a hesitation at certain points but merely a rhythm in the rate of running.

The question arises as to what relationship, if any, might be found to exist between the activity scores and final failure of the monkeys on the various steps. The

scores which would seem to be of particular interest here are the quadrant-plate ratio, the speed-of-activity scores, types of errors, and the development of the patterns.

A study of the computed activity scores (quadrants per plate, plates per minute, and quadrants per minute) revealed the fact that the scores for the failing monkeys usually lie within the range for the group which learned the step. However, in practically every case the failure scores are poorer than either the median or the average scores for the group which learned. Furthermore, with few exceptions, they are poorer than the corresponding scores for the same subject on the final step learned. The differences are small but may be of significance since they display a fairly uniform trend throughout.

A comparison of the predominating types of errors made by each individual during training on the step of final failure with the predominating types of errors made by the group which learned the step showed no striking differences for the most part.

The relationship between the development of the patterns and final failures seems to be of somewhat greater significance. Six monkeys failed before reaching Step VI. Five of these were cases in which no progress was made in learning the steps (three on Step IV and two on Step V). None of the five monkeys got beyond the first stage in pattern development. The pattern was consistently broken off with the next to the last plate of the series. In the failures occurring on Step IV, the reversal part of the pattern was not

learned, but the animals merely continued repeating the pattern which had been successful in the preceding step. The sixth monkey mentioned above was subject T, which failed on Step IV. It will be recalled that the second stage in the development of the pattern on Step IV was, as a rule, characterized by a tendency to omit plate 1 and react to the series in the order 2, 3, 2. Subject T never advanced beyond this stage. She learned the reversal part of the pattern fairly quickly but did not progress beyond the stage of omitting plate 1 although she was given 2000 trials.

Failures on all of the higher steps can be grouped into two classes: those in which the subjects made progress in learning and were nearly always successful in obtaining the food, but never succeeded in reaching the required norm of mastery, as in the cases of B, E, G, and X; and those in which they made progress in learning and then failed, due to a more or less gradual *disintegration of the habit to the point where they consistently* made failure trials, as in the cases of A, F, and V.

The group of monkeys coming under the first class of failures, without exception, did not progress beyond the second stage in pattern development. The behavior of this group was characterized by a series of partial units. The organization of the series into a single whole was not achieved.

The animals falling under the second classification differed somewhat from each other with regard to the course of pattern development. Subject V, which failed on Step XIV, showed some evidence of de-

veloping both the second and third stages of the pattern, but progress was retarded by the appearance of such antagonistic patterns as starting in the wrong direction and running around the cage without stepping on plates. The true pattern finally gave way entirely to these antagonistic patterns and the monkey made failure trials consistently until she became inactive. Subject F failed on Step X. In this case the three stages of patterned development followed each other in rapid order during the first few days of training on the step. There appeared very soon, however, a reversion to the second stage. With its reappearance, this phase took on the inferior form of completely breaking off the pattern at the second and sixth plates in the series instead of merely hesitating at these points. Later even this patterned behavior disintegrated. Subject A failed on Step XXIII. Here again patterned behavior developed to the point of frequent perfect trials and then reverted to the stage of partial patterns. A frequent shifting back and forth between second and third stages went on for a long period of time. Finally a definite tendency to omit plates at the beginning of the series developed and then frequent running around the cage without touching plates until the true pattern habit became totally disrupted.

Summary

1. The limits of learning on the Jenkins problem apparatus were found for fourteen young rhesus monkeys. The limits ranged from 2 to 22 steps, with a median of 5 and an average of 7.43. If an exception

is made of one inferior animal, the median would be raised to 6 and the average to 7.86. The differences in limits seemed to be due primarily to genuine individual differences in ability to learn.

2. The males were found to be far superior to the females in terms of the limits actually reached. The number of steps learned by the seven males ranged from 3 to 22 with a median of 9, while the number learned by the 7 females ranged from 2 to 13 with a median of 4.

3. No evidence was found for the development of a generalized solution to the problem, such as that involving "the addition of another plate" from stage to stage.

4. The learning scores (trials, errors, time) and original activity scores (plates depressed, quadrants traversed) on the advanced problem were found to be extremely variable for the individual, and for the several steps. The variability here seemed to be due, in the main, to differences in individual reaction tendencies, to differences in transfer effects from stage to stage, and to genuine individual differences in ability to learn.

5. The time and error curves on Step IV were of the usual descending type. Those for Step V and onward tended to start rather low, rise to a peak, and fall again. The initial approach to the new step thus seemed to offer less difficulty than a later part of the learning process.

6. Step IV appeared to be relatively difficult since, *first*, 4 of the 13 subjects failed at this stage, and, sec-

ond, the learning and activity scores for those subjects which did learn were, on the average, unusually poor. This would seem to be explained by the introduction into the task of a reversal in the direction of running. Beyond Step IV there appeared to be no consistency in terms of trials, errors, time, plates depressed, and quadrants traversed in the difficulty of the various steps for the group as a whole or for the individual animals.

7. No significant relationship was found between the number of steps learned and the number of trials required to learn the various steps. This was taken to mean that the two sets of scores were measuring different types of functions. The former may be regarded as somewhat analogous to the power and level tests in human work; the latter to speed of learning on tasks lying well within the range of the subjects.

8. Three stages were distinguished in the development of the patterns on each of the various steps from V to XXII. These stages were: (1) repetition of the pattern learned on the preceding step; (2) a breaking-down of the larger pattern into smaller units or partial patterns; and (3) final development of the total pattern.

V

A COMPARISON OF MONKEYS, KITTENS, AND RODENTS

It will be of interest to compare the results obtained in this study on monkeys with those secured by investigators on various other mammalian forms in the Columbia Laboratory, those by Shuey (27) on kittens and those by Riess (25) on white rats and guinea pigs, making use of the same apparatus and procedure. The procedure of Shuey differed somewhat from that used in the other studies. Instead of requiring the animals to depress plate 1 (Step I), she permitted the kittens to begin the series on any one of the three plates. Since this plan was less arbitrary, it probably made Step I somewhat easier for the kittens. This would also mean that the reversal of direction on Step IV (advanced problem B) would vary somewhat among the kittens, depending upon the direction in which they started. Moreover, the kittens were required, after learning the three steps, to learn the reversal of the series before being required to add another plate. On account of this interpolation, Step V for the kittens corresponds to Step IV for the monkeys. The extra practice on this interpolated stage may have favored the kittens on the later task on which the limits were tested. Another difference in Shuey's problem was that the second reversal came with the addition of the seventh instead of the sixth plate, as with the monkeys. No opinion can be given as to whether the difference

in the point of reversal favored the kittens or not. On the whole, the above differences in procedure in Shuey's work probably were not important enough to have influenced the average number of steps learned by the kittens, although they did doubtless influence the size of the scores. It is significant that only two of the kittens went as far as Step V, which corresponds to Step IV for the monkeys.

The limits reached (number of steps learned) by the several species can be summarized as follows:

	Range	Median	Average
Guinea Pigs	0-1	1.0	0.5
Rats	0-2	1.0	0.9
Kittens	3-7	3.0	3.6
Monkeys	2-22	5.0	7.4

The number of animals of the various groups, expressed in percentages, which learned the several steps is shown in Table 29. The percentages are based on the total number of subjects for which limits were found. As will be seen, there is relatively little overlapping except between the two groups of rodents. Only 10 per cent of the kittens did as well as 50 per cent of the monkeys, while none of the rodents did as well as 100 per cent of the kittens. Furthermore, 42.9 per cent of the monkeys went beyond Step VII, which corresponds roughly to the upper limit found for the kittens.

It is significant that Step I was found to be especially difficult for the monkeys and the kittens. The same was true of Step IV which involved the introduction of the first reversal of direction. The relative diffi-

TABLE 29

COMPARISON OF MONKEYS, KITTENS, RATS, AND GUINEA PIGS SHOWING PERCENTAGE OF SUBJECTS WHICH LEARNED THE VARIOUS STEPS

Steps learned	Monkeys	Kittens	Rats	Guinea pigs
I	100.0%	100.0%	68.6%	53.3%
II	100.0	100.0	22.9	0
III	92.9	100.0	0	
IV	64.3	20.0*		
V	50.0	20.0		
VI	50.0	10.0		
VII	42.9	10.0		
VIII	42.9	0		
IX	35.7			
X	28.6			
XI	28.6			
XII	28.6			
XIII	14.3			
XIV	7.1			
XV	7.1			
XVI	7.1			
XVII	7.1			
XVIII	7.1			
XIX	7.1			
XX	7.1			
XXI	7.1			
XXII	7.1			
XXIII	0			

*This is the result for Step V which corresponds to Step IV for the monkeys.

culty of the steps beyond this point does not follow any definite order for either the monkeys or the kittens.

The comparative scores on the several steps of the basic problem are shown for the various species in Table 30. As previously noted, there is no consistent relationship between the learning scores (trials, time) and the limits reached by the individual animal. Moreover, as shown by the table, there was no definite relationship between the learning scores and limits for the various species. For example, the guinea pigs

TABLE 30

SHOWING MEASURES OF CENTRAL TENDENCY AND VARIABILITY IN TRIALS AND MINUTES FOR MONKEYS, KITTENS, RATS, AND GUINEA PIGS ON THE VARIOUS STEPS OF THE BASIC PROBLEM

	Median	Average	Range	Average deviation	Standard deviation	Coefficient of variation
STEP I (17 MONKEYS, 62 KITTENS, 24 RATS, AND 16 GUINEA PIGS)						
Trials						
Monkeys	191.00	162.47	19-310	77.94	94.36	58.08
Kittens	42.14	46.69	9-136	17.80	25.28	54.13
Rats	196.00	221.04	30-453	99.97	125.26	56.67
Guinea pigs	151.50	185.50	53-407	110.69	176.28	95.03
Minutes						
Monkeys	210.88	306.71	17.90-970.87	222.24	279.14	91.01
Kittens	47.00	63.31	8.7 -238.0	38.73	51.35	81.10
Rats	100.37	129.39	12-230	77.09	96.59	74.65
Guinea pigs	74.40	83.28	40-191	39.19	49.10	58.96
STEP II (17 MONKEYS, 55 KITTENS, 8 RATS, AND 0 GUINEA PIGS)						
Trials						
Monkeys	60.00	169.65	12-609	139.53	189.25	111.55
Kittens	18.50	22.59	1- 70	14.01	17.23	76.27
Rats	365.00	315.25	160-450	93.19	116.77	37.04
Minutes						
Monkeys	55.57	70.00	13.65-203.73	42.27	52.12	74.46
Kittens	7.50	12.05	.1 -71.8	9.37	13.05	108.34
Rats	83.26	81.00	32-139	24.85	31.14	38.44
STEP III (16 MONKEYS, 52 KITTENS, 0 RATS, AND 0 GUINEA PIGS)						
Trials						
Monkeys	61.00	200.00	1-1640	183.63	397.88	198.94
Kittens	33.75	39.42	1-121	21-91	27.37	69.43
Minutes						
Monkeys	15.04	57.01	.12-504.07	51.29	120.32	211.05
Kittens	19.20	28.46	.2 -107.5	20.07	26.45	92.93

made lower scores than the rats did on Step I. On the whole, the scores for the kittens are much better than those for the monkeys. These facts seem to corroborate the point stressed in the earlier discussion that the scores on the several steps are measures of one thing and the indices of limits of another. It is clear also that the latter rather than the former indicate the levels of learning capacity for the individual and the species.

The question may be raised as to the significance of these comparative results. Do the limits of learning ability on this specific task represent general levels of learning capacity for the several mammalian types? This question can hardly be answered categorically at the present time. Further corroborative evidence would seem to be necessary, involving variations in this type of task and perhaps other types of tests. It is evident that rodents, kittens, and monkeys differ markedly in levels of learning capacity on this particular type of task. In view of other observations and experimental work on these forms, it seems likely that the differences indicated are representative. It seems highly probable that the order of learning ability here found indicates roughly the general level of intelligence of the species tested.

VI

GENERAL SUMMARY

A group of seventeen young rhesus monkeys were tested in the Jenkins problem apparatus on a task consisting of a series of steps of increasing complexity. The limits of learning, i.e., the most complex steps the animals were able to master, were found for only fourteen animals, since three were eliminated for reasons other than inability to learn. Each subject was transferred from one step to the next as soon as it reached the required norm of mastery (nine perfect trials out of ten) and was advanced from step to step until it failed to learn a given step. At the point of failure, the subject was eliminated from the experiment, and the last step learned was taken as the limit of ability for that animal.

For convenience, the study was divided into two parts: a basic problem consisting of the first three steps, and an advanced problem consisting of more complex patterns. In addition to limits of learning for each animal, learning scores (trials, errors, and time) were secured on each of the several steps.

The following conclusions may be drawn from these results:

1. The limits of learning ranged from 2 to 22 steps, with a median of 5 and an average of 7.43. The monkey thus appeared to be markedly superior to such mammals as the kitten as tested by Shuey (range, 3 to 7; average, 3.6), the white rat (range, 0 to 2; average,

.9), and the guinea pig (range, 0 to 1; average, .5) as tested by Riess.

2. The males were found to be definitely superior (range, 3 to 22; median, 9; average, 9.6) to the females (range, 2 to 13; median, 4; average, 5.3) with regard to number of steps learned and also with regard to speed of activity. However, this difference did not hold for scores in trials and errors, or for the quadrant-plate ratio.

3. No evidence was found for the development of a generalized solution to the problem, such as that involving "the addition of another plate" from stage to stage.

4. The differences in learning scores and in original activity scores from individual to individual and from step to step were very marked. These differences seemed to be due, in large measure, to differences in *specific reaction tendencies* of the individuals, to differences in transfer effects, and to genuine individual differences in ability to learn. In the early part of the experiment (basic problem) differences in tameness, in playfulness, and in the formation of certain stereotyped errors of the position-habit type may also have played some part.

5. It was found that the various steps of the problem on this apparatus do not progress by equal differences in difficulty. The initial formation of the plate habit would seem to account for the difficulty of Step I; the initial reversal of direction probably accounts for the difficulty of Step IV. The relative difficulty

of the other steps varied considerably from animal to animal.

6. The form of the learning curves (Vincent method) *varied considerably from step to step.* The curves (error, time) for Steps II, III, and IV were of the usual descending type. Those for Step I were in general characterized by a sharp initial rise preceding the descending trend. The curves for all of the later steps (V to XXII) also tended to start relatively low, rise to a peak, and fall again. However, in these steps the rise did not occur consistently at first.

7. No consistent relationship was found to exist between speed of learning on the several steps and the limit of learning finally reached by the individual. It was argued that the former probably measured speed of learning while the latter gave an indication of general level of ability.

8. Three stages were distinguished in the development of the patterns on each of the various steps from V to XXII. These stages were: (1) repetition of the pattern learned on the preceding step; (2) a breaking-down of the larger pattern into smaller units or partial patterns; and (3) final development of the total pattern.

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LES LIMITES DE L'APTITUDE À APPRENDRE CHEZ LES SINGES RHÉSUS

(Résumé)

On a testé 17 jeunes singes rhésus sur une tâche composée d'une série d'étapes de complexité augmentante, en employant la Boîte à Problèmes de Jenkins standardisée à Columbia University. Cet appareil comprend trois plaques de réaction, avec des fils électriques pour faire un choc, mises dans le plancher du compartiment principal. La tâche donnée aux sujets a compris la dépression d'une ou plus de ces plaques dans un ordre spécifique pour lâcher la porte du compartiment central, qui contenait de la nourriture. On a augmenté la complexité de la tâche en ajoutant des plaques, une à la fois, chaque sujet étant transféré d'une étape à la prochaine immédiatement après être arrivé à la norme requise de maîtrise (neuf épreuves parfaites sur dix), et avancé d'une étape à l'autre jusqu'à ne pas apprendre une étape donnée. A cette dernière étape on a éliminé le sujet de l'expérience, et la dernière étape apprise a été considérée la limite de l'aptitude de cet animal. Le critère de l'insuccès pour les premières étapes a été de 2000 épreuves. Pour les étapes suivantes on a employé ou 1000 épreuves actives ou 100 épreuves successives non réussies. On a employé comme stimulants un raisin sec et un morceau de pomme de même grandeur. On a maintenu une routine rigide pour le programme quotidien et l'on s'est servi constamment d'un régime standardisé. On a fait attention surtout à apprivoiser les sujets et à les adapter à l'appareil. On a exclus les stimuli troublants de l'expérimentateur et du milieu environnant à un haut degré au moyen d'un écran laissant passer la lumière d'une seule direction autour de l'appareil, du bourdonnement constant d'un éventail électrique, et des portes qui ne laissaient pas passer les sons. On a trouvé des limites pour 14 singes. Le nombre d'étapes apprises a varié de 2 à 22, avec un médiane de 5 et une moyenne de 7,43. Les singes se sont montrés très supérieurs aux mammifères tels que le chaton, le rat blanc et le cochon d'Inde, testés par d'autres sur des problèmes semblables dans le même type d'appareil. Les différences des résultats de l'apprentissage entre les divers sujets et les diverses étapes ont été très marquées. Ces différences ont semblé dues principalement aux différences dans les tendances aux réactions spécifiques chez les sujets individuels, aux différences dans les effets du transfert et à de vraies différences individuelles dans l'aptitude à apprendre. Nulle relation constante ne s'est montrée entre la vitesse de l'apprentissage des diverses étapes et la limite de l'apprentissage à laquelle le sujet individuel est enfin arrivé.

FJELD

DIE GRENZEN DER LERNFÄHIGKEIT BEI RHESUS AFFEN (MACACUS RHESUS)

(Referat)

Es wurden 17 junge Rhesus Affen an einer Aufgabe geprüft, die aus einer Aufgabenserie von stufenweise zunehmender Kompliziertheit bestand. Es wurde zu den Prüfungen der Jenkins Aufgabekasten [Jenkins Problem Box], so wie er an der Columbia University standardisiert wurde, verwendet. Dieses Apparat schliesst drei Reaktionsplatten in sich ein, die zur Heranführung eines elektrischen Schockes mit Draht versehen sind [wired for shock] und auf dem Boden des Hauptteiles des Apparates liegen. Die den Versuchstieren vorgelegte Aufgabe bestand darin, dass sie eine oder mehrere dieser Platten in einer gewissen Anordnung herabzudrücken hatten, um die Türe der zentralen Abteilung, welche Futter enthielt, frei zu legen. Die Kompliziertheit der Aufgabe wurde dadurch erhöht, dass man allmählich Platten, eine nach der anderen, hinzufügte. Jedes Versuchstier wurde von einer Stufe zu der nächsten promoviert, so bald es die erforderliche Tüchtigkeitsnorm erreicht hatte. Diese Norm bestand darin, dass von 10 Versuchen 9 perfekt ausfallen mussten, und das Tier wurde stufenweise avanciert, bis es eine Stufe erreichte, deren Bemeisterung ihm nicht gelang. Dann wurde das Tier von den Versuchen ausgeschaltet. Die letzte bewältigte Stufe galt als die Grenze der Fähigkeit [limit of ability] des in Anspruch kommenden Tieres. Auf den früheren Stufen galten 2000 Versuche als Kriterium des Fehlens [criterion of failure], auf den späteren Stufen entweder 1000 aktive Versuche oder 100 aufeinanderfolgende misglückte [successive failure trials]. Als Anspornungen dienten eine Rosine und ein Stück Apfel von der selben Grösse. In Bezug auf das tägliche Programm wurde streng an eine Routine und an eine Normaldität gehalten. Man achtete besonders darauf, die Versuchstiere zu zähmen und sie dem Apparat anzupassen. Verwirrende Reize von Seite des Versuchsleiters oder der Umgebung wurden in hohem Masse ausgeschaltet durch einen einseitigen [one-way] das Apparat umgebenden Lichtschirm [light screen], das beständige Summen eines elektrischen Fächers, und lärmstillende [sound-proof], in das Versuchszimmer hineinführende Türe. Es wurden die Grenzen der Lernfähigkeit an 14 Affen bestimmt. Die Zahl der bemeisterten Stufen variirte zwischen 2 und 22. Die Mittelzahl [median] betrug 5 und die Durchschnittszahl 7.43. Die Affen erwiesen sich als anderen Säugetieren, wie zum Beispiel Kätzchen, weissen Ratten, und Meerschweinchen, bestimmt überlegen. (Diese anderen Säugetiere sind von anderen Versuchsleitern an ähnlichen Aufgaben mit der selben Art von Apparat geprüft worden.) Es zeigten sich ausgeprägte Unterschiede zwischen den von verschiedenen Versuchstieren und an verschiedenen Stufen in den Prüfungen erzielten Zahlen [learning scores]. Diese Unterschiede schienen grossenteils durch Unterschiede in Bezug auf besondere Reaktionsneigungen [reaction tendencies] der individuellen Versuchstiere, Unterschiede in Bezug auf die Einwirkungen der Übertragung [transfer effects] (Übertragung des Gelernten auf neue Aufgaben), und echte individuelle Unterschiede in Bezug auf Lernfähigkeit bestimmt zu sein. Man fand keine beständige Beziehung zwischen der Schnelligkeit, mit der die einzelnen Stufen erlernt wurden, einerseits, und der von dem individuellen Versuchstier schliesslich erreichten Grenze der Lernfähigkeit anderseits.

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